**To:** Indur Goklany[indur_goklany@ios.doi.gov]
**Cc:** Jonathan Steele[jonathan_steele@ios.doi.gov]; Shawn Buckner[shawn_buckner@ios.doi.gov]
**From:** Gulac, Catherine
**Sent:** 2016-11-17T10:47:37-05:00
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**Subject:** Fwd: LEGISLATIVE REFERRAL: (DUE 11/21/16 @ 5 PM) MISC #229 - CDC & ASPR Questions for the Record from 4/14/16 Hearing Re: The Federal Perspective on the State of Our Nation's Biodefense
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SS004.1--ASPR Biodefense QFR Draft.docx
SS004.2--CDC Biodefense QFR Draft.docx

*Catherine Gulac*
U.S. Department of the Interior
Office of the Deputy Secretary
1849 C St, NW, MS-7328
Washington, D.C. 20240
202-208-6291 Office / 202-208-1739 Direct / 202-208-1873 Fax
Catherine_Gulac@ios.doi.gov

---------- Forwarded message ----------
From: **Nevils, Joseph** <joseph_nevils@ios.doi.gov>
Date: Thu, Nov 17, 2016 at 10:46 AM
Subject: LEGISLATIVE REFERRAL: (DUE 11/21/16 @ 5 PM) MISC #229 - CDC & ASPR Questions for the Record from 4/14/16 Hearing Re: The Federal Perspective on the State of Our Nation's Biodefense
To: Benjamin Milakofsky <benjamin_milakofsky@ios.doi.gov>, DS <gareth_rees@ios.doi.gov>, OIG <Lori_Vassar@doioig.gov>, OIG <bruce_delaplaine@doioig.gov>, OIG <nancy_dipaolo@doioig.gov>, OCL Office <sarah_neimeyer@ios.doi.gov>, OCL Office <felipe_mendoza@ios.doi.gov>, OCL Office <chelsea_welch@ios.doi.gov>, A/S-PMB <David_Downes@ios.doi.gov>, A/S-PMB <Amy_Holley@ios.doi.gov>, A/S-PMB <Debra_Sonderman@ios.doi.gov>, A/S-PMB <Denise_Flanagan@ios.doi.gov>, A/S-PMB <Abigail_D_Miller@ios.doi.gov>, A/S-PMB <Olivia_Ferriter@ios.doi.gov>, A/S-PMB <Elizabeth_Klein@ios.doi.gov>, PPA <Catherine_Gulac@ios.doi.gov>, POB <adrianne_moss@ios.doi.gov>, POB <jason_freihage@ios.doi.gov>, POB <tiffany_taylor@ios.doi.gov>, POB <patrick_joos@ios.doi.gov>, PEP <david_behler@ios.doi.gov>, PEP <maryjosie_blanchard@ios.doi.gov>, PEP <michaela_noble@ios.doi.gov>, A/S-IN <nikolao_pula@ios.doi.gov>, A/S-IN <Stephen_Sander@ios.doi.gov>, A/S-IN <esther_kiaaina@ios.doi.gov>, A/S-IN <basil_ottley@ios.doi.gov>, A/S-IN <wendy_clerinx@ios.doi.gov>, A/S-IA <Liberty.Metcalf@bia.gov>, A/S-IA <Darren.Pete@bia.gov>, A/S-IA <Karen.Frazier@bia.gov>, A/S-FW <karen_hyun@ios.doi.gov>, A/S-FW <craig_dorsett@ios.doi.gov>, FWS <megan_kelhart@fws.gov>, FWS <dana_bivens@fws.gov>, FWS <lisa_m_jones@fws.gov>, FWS <alyssa_hausman@fws.gov>, FWS <Roya_Mogadam@fws.gov>, FWS <Martin_Kodis@fws.gov>, FWS <angela_gustavson@fws.gov>, FWS <edith_thompson@fws.gov>, NPS <Sarah_Gamble@nps.gov>, NPS <Susan_Farinelli@nps.gov>, NPS <Melissa_Kuckro@nps.gov>, A/S-WS <thomas_iseman@ios.doi.gov>, A/S-WS <camille_touton@ios.doi.gov>, A/S-WS <mariacamille_touton@ios.doi.gov>, USGS <jjester@usgs.gov>, USGS <egoldbaum@usgs.gov>, USGS <david.diamond@boem.gov>, USGS <bjcole@usgs.gov>,

USGS <jonizuk@usgs.gov>, USGS <ctrent@usgs.gov>, USGS <wlukas@usgs.gov>, BOR <MMAUCIERI@usbr.gov>, BOR <DEThompson@usbr.gov>, BOR <RWolf@usbr.gov>, BOR <aadler@usbr.gov>, BOR <rweil@usbr.gov>, A/S-LM <Richard_Cardinale@ios.doi.gov>, A/S-LM <Pam.Royal@boemre.gov>, A/S-LM <james_lyons@ios.doi.gov>, A/S-LM <janice_schneider@ios.doi.gov>, A/S-LM <lauren_bogard@ios.doi.gov>, A/S-LM <amanda_leiter@ios.doi.gov>, A/S-LM <pam.royal@bsee.gov>, BLM <William_E_Holmes@blm.gov>, BLM <michelle_reid@blm.gov>, BLM <ledouglas@blm.gov>, BLM <dblackst@blm.gov>, BLM <kkelleh@blm.gov>, BLM <begruber@blm.gov>, BLM <jralston@blm.gov>, BLM <wholmes@blm.gov>, BLM <mareid@blm.gov>, SOL <Marigrace.Caminiti@sol.doi.gov>, SOL <edward.keable@sol.doi.gov>, SOL <Robert.Johnston@sol.doi.gov>, SOL-GL <rachel.spector@sol.doi.gov>, SOL-GL <timothy.murphy@sol.doi.gov>
Cc: OCL Office <Chris_Salotti@ios.doi.gov>, OCL Office <Dominic_Maione@ios.doi.gov>

**DEADLINE: MONDAY, NOVEMBER 21, 2016 @ 5 PM**

**DEPARTMENT OF THE INTERIOR**

**LEGISLATIVE COUNSEL REFERRAL**

**Date:** **November 17, 2016**

**To:** **Legislative Liaison**

**From:** **Dominic Maione (208-4092)**

**Contact:** **Joe Nevils (208-4580)**

**Subject:** **MISC #229 - CDC & ASPR Questions for the Record from 4/14/16 Hearing Re: The Federal Perspective on the State of Our Nation's Biodefense**

**Attached please find draft QFRs for CDC (Redd) and HHS/ASPR (Hatchett) from a April 14, 2016 hearing on Federal Perspectives on the State of Our Nation's Biodefense before the Senate Homeland Security and Government Affairs Committee.**

**Please see notes below and review the QFRs and respond by the deadline above.**

**NOTES:**

**The 25 page draft HHS/ASPR QFRs discuss the coordination of medical preparedness and response efforts within HHS**

**and with other interagency and external stakeholders, the Disaster Leadership Group, the National Security Council's Interagency Policy Committee, the Americas Region Interagency Coordination Group, placing the Zika virus on FDA's Priority Review Voucher program list of qualifying Neglected Tropical Diseases, BARDA's work in response to Zika, Zika vaccine development and WRAIR's role in the development process, intelligence products related to biodefense, biosurveillance programs, viruses circulating in animals that could impact human health, the importance of communicating risk-related information to state and local partners during a public health emergency, the cybersecurity of health care and public health sector organizations, DoD and HHS collaborationand coordination on military and civilian biodefense, NSC's Biosurveillance Sub-Interagency Policy Committee, licensing rights for patentable inventions that result from the development of medical countermeasures, and Anthrax countermeasures. At various points the QFRs discuss, defer to, or otherwise mention: CDC, FDA, NIH, NSC, DoD, USDA, DOI, DHS, DOJ (including FBI), and EPA.**

**The 25 page draft CDC QFRs discuss CDC's coordination efforts in responding to Zika, placing the Zika virus on FDA's Priority Review Voucher program list of qualifying Neglected Tropical Diseases, CDC assisting Wisconsin during the Elizabethkingia investigation, the One Health concept (including leveraging the expertise of the USGS National Wildlife Health Center), CDC's overarching surveillance strategy, planning for animal and zoonotic outbreaks, resources provided to emergency responders to keep them safe, guidance on medical countermeasure planning requirements for state and local partners, protecting sensitive data, the Federal Select Agent Program, funding, the National Biosurveillance Strategy, Ebola, and Anthrax. At various points the QFRs discuss, defer to, or otherwise mention many of the agencies ASPR refers to, as well as: VA, State Department, and OSTP.**

**Please send agency comments or respond with a "no comment" to Dominic_Maione@ios.doi.gov and Joseph_Nevils@ios.doi.gov by the deadline above.**

Attachment(s): 2

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**Joseph Nevils**
Legislative Assistant

Department of the Interior
1849 C St, NW 20240
(202) 208-4580 (O)
(202) 208-7619 (F)

**<u>Questions for the Record</u>**

**Senate Committee on Homeland Security and Governmental Affairs**

***Federal Perspective on the State of Our Nation's Biodefense***
**Thursday, April 14, 2016**

**Dr. Richard Hatchett**
**Acting Director, Biomedical Advanced Research and Development Authority**
**Office of the Assistant Secretary for Preparedness and Response, U.S. Department of Health and Human Services**

**<u>Senator Kelly Ayotte</u>**

1) **On April 13, the Centers for Disease Control and Prevention (CDC) announced that there is now definitive evidence that the Zika virus causes microcephaly and other serious brain defects in infants. The CDC also estimated that up to 30 percent of women in infested areas may eventually contract Zika. Our neighbors in Puerto Rico have already been severely impacted by the virus. There have been travel-associated cases of Zika in my home state of New Hampshire.**

    a. **How is your department coordinating with other relevant federal agencies, as well as state departments of health and health departments in Puerto Rico, the U.S. Virgin Islands, and American Samoa in the fight against Zika?**

The Assistant Secretary for Preparedness and Response (ASPR) serves as the principal advisor to the Secretary of Health and Human Services (HHS) on matters relating to federal public health and medical preparedness in response to public health emergencies. In this capacity, ASPR coordinates medical preparedness and response efforts within the Department of Health and Human Services (HHS) and collaborates with other interagency and external stakeholders such as state/territory and local health departments. One of ASPR's first acts in addressing the emerging Zika threat was to activate the Disaster Leadership Group (DLG). Comprised of senior leaders from across HHS, the DLG instigates information sharing and coordination in areas such as communications, laboratory capacity, medical countermeasure (MCM) development, domestic preparedness, blood/tissue/organ safety, and collaboration with international partners.

ASPR also leads the HHS Sample Sharing Working Group which has been collecting domestic and international samples from individuals with confirmed Zika virus infection. Likewise, ASPR's Hospital Preparedness Program has field officers in each HHS Region around the country to provide technical assistance, best practices, and grant support to regional health care coalitions. The field officers responsible for Puerto Rico, the U.S. Virgin Islands, and American Samoa are working to develop and implement strategies to prepare and coordinate care for patients with Zika virus. ASPR is also working with the Puerto Rico Department of Health to plan for any increase in the number of cases of Guillain-Barré syndrome, a condition associated with Zika virus infection. This includes recommendations such as regionalizing specialty care,

exploring ways to augment available staffing, and surveying the potential for telehealth and/or telemedicine resources.

One example of ASPR's leadership involves coordinating efforts to support Puerto Rico's blood supply. On March 5, 2016, blood collection in Puerto Rico was suspended based on guidance issued by the Food and Drug Administration (FDA) on February 16, 2016. The guidance included a recommendation that areas with active Zika virus transmission obtain whole blood and blood components from areas of the United States without active virus transmission until a blood donor screening test or pathogen reduction technology for Zika virus becomes available ASPR, the Office of the Assistant Secretary for Health, FDA, and the Centers for Disease Control and Prevention (CDC) worked quickly to establish blood supply contracts with the American Red Cross and Blood Centers of America. HHS agencies were asked to assist on February 26, 2016, and contracts were awarded five days later on March 2, 2016. This made it possible for Puerto Rico's 11 blood establishments to receive weekly shipments of blood products. The contracts initiated by ASPR ensured an adequate supply of safe blood for residents and provided additional time for the 11 blood establishments to implement testing of all donations with an investigational blood donor screening test for Zika virus, which has been in use in Puerto Rico since early April 2016.

**b. Has there been a formal plan developed that is comprehensive in nature and that focuses on interagency coordination at the state and federal levels, prevention, and response?**

The National Response Plan guides the federal response effort and prioritizes close coordination among partners. ASPR coordinates preparedness, response, and recovery efforts across the Department and the interagency under that plan. Specifically, for the Zika virus response, ASPR serves as the primary lead for critical policy decisions and identifying potential barriers for an effective response.

**c. If so, could you provide details that demonstrate how these agencies are working together?**

ASPR coordinates interagency efforts to address the Zika virus through the DLG. Within ASPR, the HHS Secretary's Operations Center has been activated to respond to Zika in close coordination with CDC's Emergency Operations Center. ASPR also leads the coordination and reporting of ongoing situational awareness information to senior federal officials. In addition, ASPR coordinates with other United States Government (USG) departments via the National Security Council's Interagency Policy Committee (IPC) and sub-IPC on Zika.

ASPR's Biomedical Advanced Research and Development Authority (BARDA) has been collaborating with CDC, FDA, and the National Institutes of Health (NIH) to facilitate the development of rapid point-of-care and laboratory-based serological assays to determine who has been previously infected by Zika (especially pregnant women). ASPR/BARDA has also been working with CDC, FDA, and NIH to facilitate the development of commercial assays to identify Zika infection.

Building on partnerships and lessons learned from the H1N1 and Ebola responses, ASPR is implementing a Zika MCM strategy through the advanced development and manufacturing of new Zika vaccine candidates. In collaboration with NIH, FDA, and the Walter Reed Army Institute of Research (WRAIR), ASPR is working on Zika vaccine development, preclinical and clinical testing, and commercial scale production, including vaccine manufacturing through the Centers for Innovation in Advanced Development and Manufacturing (CIADM). ASPR supports industry partners in developing new vaccine platform technologies applicable to multiple emerging infectious diseases, including new Zika vaccine candidates.

On the international front, ASPR and the HHS Office of Global Affairs re-convened the USG Americas Region Interagency Coordination Group. This group serves as a forum for USG partners to share information and coordinate Zika preparedness and response efforts among themselves and with the Pan American Health Organization. In this case, the group has a particular focus on aligning responses to Zika-related international requests for assistance. International coordination also involves outreach to various Ministries of Health to establish public health and scientific research collaboration agreements and obtain Zika samples that help isolate the virus and validate serological diagnostics assays. ASPR is also providing technical assistance to global partners in Brazil for Zika vaccine development and commercial scale manufacturing.

2) **About a month ago, Senator Burr and I wrote to FDA to urge the agency use its authority to place Zika virus on the FDA's Priority Review Voucher program list of qualifying Neglected Tropical Diseases. Such a designation would help accelerate much needed research on Zika and even potentially lead to a Zika vaccine or treatment by leveraging private investment. In 2014, I cosponsored a bill that was signed into law which placed Ebola on the same priority review list.**

   **In their response to our letter, the FDA noted that it did not believe the Zika virus met the criteria for the Priority Review Voucher program because there "appears to be a significant market for Zika virus medical products in developed nations" thereby making Zika ineligible for the program. I was disappointed in this response.**

   a. **Do you disagree with the FDA's finding that Zika would not be a good candidate for its Priority Review Voucher program?**
   b. **Can you put into context the threat that Zika poses versus our current ability to mitigate the spread of the virus?**
   c. **Shouldn't that be a key component when considering ways to expedite the ability to produce a safe and effective vaccine or an improved diagnostic test?**

S. 2512, signed into law on April 19, 2016, adds the Zika virus to the list of tropical diseases included under the FDA Priority Review Voucher Program. Please see the responses from Dr. Stephen Redd, who testified on behalf of CDC and is responding to these questions on behalf of HHS agencies.

3) **In its response to our letter, the FDA also stated that BARDA has activated its National Medical Countermeasures Response Infrastructure in order to provide direct assistance**

**to product developers for vaccine and diagnostic test development and manufacturing. Could you provide me with a more detailed status update on the work that BARDA is doing related to Zika, including how you are coordinating with both relevant federal and state agencies?**

In response to the Zika outbreak, BARDA mobilized the National Medical Countermeasures Response Infrastructure in early 2016. The Response Infrastructure is comprised of three CIADMs, the Fill-Finish Manufacturing Network, the Nonclinical Development Network (NDN), and the Clinical Studies Network (CSN). Collectively, they provide manufacturers and Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) partners with critical support before, during, and after national health emergencies.

BARDA mobilized the CSN to assist with sample collection for the development of Zika diagnostic validation panels. Specifically, the CSN worked to secure clinical serum specimens from Zika infected individuals in both the continental U.S. and its territories, and to provide these specimens to diagnostic test developers. Four of the five CSN participants provided proposals outlining the technical details, timelines, and costs for fulfilling this requirement. Samples were collected in Puerto Rico, New York, Florida, and Texas, in conjunction with CDC and local, state, and regional public health departments.

With respect to Zika vaccines, BARDA is collaborating with the National Institute of Allergy and Infectious Diseases (NIAID) and WRAIR to develop a purified inactivated Zika virus vaccine. The candidate vaccine was chosen based on WRAIR's experience with this viral inactivation platform, which has been used to develop many other flavivirus vaccines including a tetravalent Dengue vaccine. The inactivated Zika vaccine, developed and produced by WRAIR with support from NIAID, has shown 100 percent efficacy in mice and monkeys and has reached the final stages of manufacturing in preparation for clinical trials. Four clinical trials are being planned for the fall of 2016: one at WRAIR, one funded by WRAIR at Beth Israel Deaconess Medical Center, one through NIAID's Vaccine and Treatment Evaluation Unit network, and one in collaboration with the NIAID Vaccine Research Center. Most candidate vaccines are in early stages of development, and work is currently underway at BARDA's Nonclinical and Clinical Development Networks to generate essential reagents for vaccine and diagnostics manufacturers.

The ability to rapidly pivot from the preclinical development of a candidate vaccine or therapeutic to manufacturing for clinical evaluation is a significant accomplishment when confronting a rapidly evolving epidemic. In early 2016, the CIADMs were activated to support the government's coordinated response to the Zika virus outbreak in South America. Specifically, one of BARDA's CIADM partners repositioned assets to help collect materials to screen potential cell-based platforms for a Zika virus vaccine candidate. Likewise, in June, BARDA awarded a task order to the Emergent BioSolutions CIADM in Baltimore, Maryland, to develop a whole virus inactivated Zika vaccine candidate.

Plans are under way to engage the NDN to develop appropriate animal models of Zika virus infection to facilitate MCM development.

<u>**Senator Thomas Carper**</u>

**1) In its 2011 report, the General Accounting Office reported that there is no individual or entity with responsibility, authority, and accountability for overseeing the entire biodefense enterprise and recommended that the Homeland Security Council consider establishing a focal point to oversee these efforts. The number one recommendation included in the Bipartisan Report of the Blue Ribbon Study Panel on Biodefense is to institutionalize biodefense in the Office of the Vice President of the United States to ensure that biodefense will be addressed by every Administration at the highest levels. The second recommendation is to establish a Biodefense Coordination Council at the White House, led by the Vice President.**

**a. Do you support establishing one individual or entity to coordinate these efforts or think that the existing structure is sufficient?**

With respect to the medical and public health response, the Office of the Assistant Secretary for Preparedness and Response (ASPR) supports a bottom-up approach to biodefense issues where multiple interagency partners pool their resources and capabilities to identify threats and formulate response plans. Effective structures exist now under the ASPR to coordinate the public health and medical components of our biodefense preparedness. The ASPR leads the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE), which is a medium for interagency partners to discuss and combine resources that produce medical countermeasures (MCM) for identified and suspected bio threats. The ASPR also leads the Disaster Leadership Group (DLG), which engages with key leadership from across the Department of Health and Human Services (HHS) to share information and coordinate preparedness and response activities. Both the DLG and PHEMCE are working effectively to coordinate these efforts across the Department and interagency. However, ASPR recognizes that medical and public health is only a component of a larger national biosecurity preparedness and response effort and interagency groups and White House play key roles in that larger coordination.

**b. How else could we improve coordination across the government in biodefense activities?**

As the principal advisor to the Secretary on matters relating to federal public health and medical preparedness in response to public health emergencies, ASPR consistently works on improving biodefence coordination through structures such as the PHEMCE and DLG.

**2) In its final report, the Blue Ribbon Study Panel issued more than 33 recommendations for action by the Executive Branch. Please explain what activities your Department or Agency is taking to address the select recommendations listed below from the report and note whether the activities have begun, are completed or have not yet started. Please also note recommendations that you do not intend to fulfill and why not. Please provide a response for each recommendation below that applies to your Department or Agency:**

**a. #6 – Improve management of the biological intelligence enterprise.**

HHS/ASPR is a consumer, not a producer, of intelligence products related to biodefense. This recommendation is best directed to those in the Intelligence Community.

**b. #7 – Integrate animal health and One Health approaches to biodefense strategies.**

This recommendation is best directed to the U.S. Department of Agriculture (USDA), and the Department of Interior (DOI). However, HHS recognizes that the concept of One Health is important to a variety of public health issues, especially the emergence or re-emergence of naturally occurring infectious diseases.

A variety of pathogen threats identified by the Department of Homeland Security (DHS) and detailed in the PHEMCE Strategy and Implementation Plan are also zoonotic agents. Medical or veterinary information gleaned from these specific pathogens enhances MCM assessments.

**c. #8 – Prioritize and align investments in medical countermeasures among all federal stakeholders.**

Prioritizing federal resources is necessary given the range of potential threats and available resources. With that in mind, the PHEMCE developed a coordinated and strategic framework in 2012 to direct MCM investments. PHEMCE agencies work together to ensure that MCM products progress as quickly and economically as possible from early to final stage development. If needed, these products are purchased for the Strategic National Stockpile (SNS) and used effectively in an emergency. For instance, the PHEMCE framework was utilized during the Ebola response when partners leveraged assets across the federal government to support the development and evaluation of Ebola candidate vaccines and treatments.

The PHEMCE prioritization framework is based on two core principles: (1) a medical and public health obligation to limit adverse health effects from a variety of threats; and, (2) a responsibility to be prudent with the financial resources while maximizing national preparedness. The PHEMCE will continue to apply this framework to inform federal resource allocations for research, development, manufacturing, procurement, and effective utilization of MCMs. The annual PHEMCE multi-year budget report prioritizes criteria to coordinate a five-year budget plan to research, develop, procure, and stockpile MCMs.

The PHEMCE works diligently to identify and prioritize investments among federal stakeholders. Examples of these processes include:

1. An annual report to Congress from the HHS Secretary prioritizing products maintained or accessed by the SNS.
2. An annual PHEMCE Strategy and Implementation Plan with anticipated completion timelines and recent accomplishments to outline priority actions and responsible organizations.
3. An annual multi-year budget identifying how agencies manage MCM lifecycle costs to collaborate and move products from research and development into approval, acquisition, and stockpiling. It is designed to help agencies understand and forecast impacts on their anticipated budgets. This approach provides actual costs based on the current fiscal year budget, the President's approved budget estimate for the next fiscal year, and projected requirements for the following three years.

4. Ongoing portfolio reviews across all chemical, biological, radiological, nuclear (CBRN) and pandemic threat areas to review detailed priorities and identify gaps and challenges. More specifically, to identify where resources may be better arrayed to address the appropriate challenge.
5. A product tracking tool for all contracts from agencies engaged in product development. This provides a real-time assessment of candidate products from the basic science level towards final regulatory approval and completion. The product tracking tool is available now for all vaccines, therapeutics, diagnostic efforts, and other related contracts across the PHEMCE.

**d. #9 – Better support and inform decisions based on biological attribution.**

This recommendation relates to intelligence gathering and law enforcement activities that are beyond HHS's scope of authority and is best directed to DHS, the Department of Justice, the Federal Bureau of Investigation (FBI), and other members of the Intelligence Community.

**e. #10 – Establish a national environmental decontamination and remediation capacity.**

This recommendation is best directed to the Federal Emergency Management Agency (FEMA) and the Environmental Protection Agency as the lead agencies for the development of a national decontamination and remediation capacity, with the involvement of HHS. HHS, through CDC, has conducted hazardous materials response capacity building, including decontamination training, through the FEMA facility in Anniston, Alabama. The Department, through CDC, is also involved in other planning processes that include decontamination components, such as the Chemical Incident Annex Planning.

**f. #11 – Implement an integrated national biosurveillance capability.**

See response to question 2h.

**g. #12 – Empower non-federal entities to be equal biosurveillance partners.**

See response to question 2h.

**h. #13 – Optimize the National Biosurveillance Integration System.**

ASPR does not manage biosurveillance programs. However, as the lead for HHS's public health and health care preparedness and response activities, ASPR is a consumer of biosurveillance information which helps direct PHEMCE priorities. ASPR served as a co-chair on the DHS/Office of Health Affair's National Biosurveillance Integration Center's Advisory Board, which allows for collaboration amongst all federal partners who conduct biosurveillance activities and provides guidance for enhancing the National Biosurveillance Integration System.

**i. #14 – Improve surveillance of and planning for animal and zoonotic outbreaks.**

HHS works with USDA and DOI on viruses circulating in animals that could impact human health, such as highly pathogenic avian influenza (HPAI) outbreaks. Specifically, HHS is

responsible for sustaining a capability to produce a pandemic vaccine at any time of the year in a U.S.-licensed influenza vaccine facility. With that in mind, ASPR contracted with Sanofi Pasteur, the major domestic supplier of egg-based influenza vaccine, to ensure year-round availability. This includes enough embryonated eggs to produce 10 million monovalent doses per week.

In order to maintain this investment and capability, ASPR's Biomedical Advanced Research and Development Authority (BARDA) has been working to improve planning for animal and zoonotic outbreaks. During the 2015 HPAI outbreak, BARDA communicated daily with Sanofi Pasteur for updates and information from the USDA and the Pennsylvania Department of Agriculture. In addition, BARDA participated in several HPAI roundtable exercises initiated by Sanofi Pasteur and its egg supply subcontractors. These roundtable exercises highlighted the interagency, intra-agency and private industry cooperation, communication, and clarification of issues related to the safety, supply, and transportation of embryonated eggs for vaccines during an HPAI outbreak.

**j. #15 – Provide emergency responders with the resources they need to keep themselves and their families safe.**

ASPR offers a number of educational resources to emergency responders, such as the ASPR Technical Resources, Assistance Center, and Information Exchange (TRACIE) and the CBRN toolkit. In addition, ASPR's Office of Emergency Management (OEM) conducts training programs to improve the readiness and safety of emergency responders, including National Disaster Medical System and the Counter-Narcotics and Terrorism Operational Medical Support program training activities.

ASPR has released a funding opportunity announcement entitled "Enhance the Ability of Emergency Medical Services to transport patients with highly infectious diseases" to assist in the development of a state Emergency Medical Services High Consequence Infectious Disease Transport Plan Template. This plan will help reduce the risks for personnel required to transport patients with highly lethal or communicable infectious diseases.

**k. #16 – Redouble efforts to share information with state, local, territorial, and tribal partners.**

HHS's Ebola response highlighted the importance of communicating risk-related information to state and local partners during a public health emergency. To ensure that stakeholders have access to critical and up-to-date information to better support emerging needs during disaster, ASPR launched the Technical Resources Assistance Center and Information Exchange (TRACIE) in September 2015. TRACIE provides one-stop shopping for partners and stakeholders to gain access to best practices, guidance documents, and technical assistance as well as to share ideas and to collaborate with stakeholders on matters pertaining to healthcare emergency preparedness. TRACIE ensures that stakeholders at all levels of government and the private sector have access to information and resources to improve preparedness, response, recovery, and mitigation efforts. TRACIE's listserv has nearly 4000 recipients, has received over 30,000 visitors to the website, responded to more than 300 training and technical assistance requests, and signed up nearly 1200 members to the Information Exchange.

In addition, ASPR's U.S. International Health Regulations (2005) National Focal Point provides bidirectional information sharing between domestic and international partners concerning potential international public health emergencies. This notification and reporting process involves federal, state, local, territorial, and tribal stakeholders.

**l. #18 – Establish and utilize a standard process to develop and issue clinical infection control guidance for biological events.**

Please see the responses from Dr. Stephen Redd, who testified on behalf of CDC and is responding to this question on behalf of HHS agencies.

**m. #22 – Develop and implement a Medical Countermeasure Response Framework.**

Please see the responses from Dr. Stephen Redd, who testified on behalf of CDC and is responding to this question on behalf of HHS agencies.

**n. #23 – Allow for forward deployment of Strategic National Stockpile assets.**

Please see the responses from Dr. Stephen Redd, who testified on behalf of CDC and is responding to this question on behalf of HHS agencies.

**o. #24 – Harden pathogen and advanced biotechnology information from cyber attacks.**

ASPR's Critical Infrastructure Protection Program works closely with the private sector to improve the cybersecurity of health care and public health sector organizations, including laboratories, pharmaceutical manufacturers, and others that might handle biotechnology information. ASPR shares information with private sector organizations on cyber threats and works in close collaboration with other federal partners such as DHS and the FBI. ASPR is also leading the Health Care Industry Cybersecurity Task Force, which was established as part of the implementation of the Cybersecurity Information Sharing Act of 2015.

**p. #26 – Implement military-civilian collaboration for biodefense.**

The Department of Defense (DoD) and HHS collaborate and coordinate military and civilian biodefense and MCM efforts under the PHEMCE. Through the PHEMCE, DoD and HHS collaborate and share information on research, advanced research, development, procurement, stockpiling, and distribution of MCMs. DoD and HHS both have voting membership within the PHEMCE at multiple levels. Additionally, DoD participates in all In-Process Reviews conducted for ASPR/BARDA programs and PHEMCE-wide portfolio reviews led by ASPR.

The PHEMCE Integrated Portfolio for CBRN MCMs was established within the PHEMCE in 2008 to provide a framework for collaboration among the MCM-related program components of HHS and DoD. The Portfolio Advisory Committee, co-chaired by DoD and HHS, is comprised of program representatives from various organizations responsible for the CBRN MCM programs within each department. Through the Portfolio Advisory Committee, DoD and HHS coordinate efforts to promote synergy, minimize redundancy, and, to the extent feasible,

harmonize requirements for MCM development. A significant example of collaboration is the development of the Portfolio Tracking Tool, developed jointly by HHS and DoD to capture contract performance information for all CBRN MCM development efforts across both agencies.

ASPR/BARDA program managers participate in a number of DoD Integrated Product Teams, including those specifically associated with CBRN MCMs. Moreover, senior level individuals participate in DoD's Joint Program Executive Office for Chemical and Biological Defense Joint Life Cycle Management Reviews, and in various In-Process Reviews (for all DoD MCM programs), as well as on the DoD Overarching Integrated Product Team. The 2014 Ebola epidemic response demonstrated the effectiveness of the DoD and HHS relationship. CDC and DoD worked together to develop and implement Ebola diagnostics in West Africa and in U.S. laboratories. DoD also successfully transitioned Ebola vaccine and therapeutic candidates from early development to ASPR/BARDA for advanced development.

Beyond information sharing, DoD and HHS also coordinate on the research, development, and procurement of safe and effective MCMs. DoD and CDC collaborate closely on the acquisition and management of MCMs for anthrax and smallpox while ASPR/BARDA and DoD collaborate on the acquisition and management of pre-pandemic influenza vaccines. HHS and DoD are jointly developing MCMs for chemical threats and to address gastrointestinal injury associated with acute radiation syndrome.

**q. #27 – Prioritize innovation over incrementalism in medical countermeasure development.**

The PHEMCE has prioritized innovation as a central component of it approach to product development. This is especially true when developing vaccines to address novel strains that require rapid shifts in product development. Innovation goes hand-and-hand with instrumentalism including the rapid development of candidate vaccine materials from early genomic sequencing of novel strains and genetic construction. This can now be accomplished in days as opposed to standard re-assortment methods that may require weeks of effort. Other innovations in how products are screened for microbial contaminants (sterility) have been recently developed under the auspices of ASPR/BARDA and the PHEMCE, and may result in changing the way the entire pharmaceutical industry conducts such screening.

In addition, the PHEMCE has invested in a variety of novel concepts and innovations such as the development of a new ventilator that is small, cheap, and has a broad capability to assist in ventilating patients from infants to adults. The PHEMCE has enhanced the regulatory review processes by investing in regulatory research and prioritizing the review of key products for biodefense and radiological defense. Innovations in new adjuvants have occurred that are first in use for influenza vaccines and expand the very limited number of previously acceptable vaccine adjuvants.

**r. #28 – Fully prioritize, fund, and incentivize the medical countermeasure enterprise.**

This recommendation is best addressed by the President and the Congress. However, PHEMCE agencies contribute to the appropriations process by identifying and quantifying MCM requirements. The Pandemic and All-Hazards Preparedness Reauthorization Act of 2013

requires HHS to develop a five-year budget plan for the medical countermeasure enterprise. This multiyear plan is a tool for strategic project coordination, product transitions between agencies, communication of priorities and resources to partner stakeholders, and assistance with long-term forecasting. The goal of the multiyear plan is to outline PHEMCE programmatic estimates on a five-year rolling basis and to identify the hand-offs in the development cycle in anticipatable budget terms. This forecast allows agencies to understand the dynamic effects of PHEMCE decisions on their own strategic planning and those of downstream partners. Additionally, this tool communicates PHEMCE commitments and priorities to our industry partners. By coordinating resources and priorities, we can ensure an active medical countermeasure industry that meets our essential needs for a nimble and flexible response capability.

The HHS MCM requirement process serves to improve the outcomes of public health emergencies by focusing federal investments toward an aligned research, advanced development, acquisition, deployment, and use by PHEMCE-partner agencies including the National Institutes of Health (NIH), ASPR/BARDA, the U.S. Food and Drug Administration (FDA), and CDC. The requirement process informs private industry and academia about civilian MCM needs and facilitates effective coordination of programs with PHEMCE interagency partners. From there, the desired product volume and stockpiling goals provide critical information to support the PHEMCE leadership's allocation of resources. Prior to making investment decisions and pursuing specific acquisition targets, the PHEMCE considers MCM needs across the entire threat portfolio, along with scientific opportunity, existing resources, and other factors.

**s. #29 – Reform Biomedical Advanced Research and Development Authority contracting.**

ASPR's current line of authority, which includes a separate and specialized Office of Acquisitions Management, Contracts, and Grants (AMCG), appropriately distinguishes the roles and responsibilities of a certified and warranted acquisition workforce from program and scientific experts. This line of authority ensures proper checks and balances for effectively managing taxpayer investments through open and fair competition and is fully consistent with comparable agencies in the federal government. This also defuses potential or perceived concerns about conflicts of interest and corresponding legal problems, and helps avoid any appearance of undue command influence by an individual, program office, or outside source on contracting.

AMCG is an award winning and innovative contracting office that has received the HHS Secretary's 2015 Hubert H. Humphrey Award for Service to America, the 2012 HHS Small Business Award, and 2010 HHS Project Team Award for its contribution to the H1N1 Influenza Virus response. In addition, AMCG incorporated Broad Agency Announcements, which streamlined the acquisition process and initiated the use of Other Transaction Authority to further engage industry.

AMCG has also led the Department in meeting contracting deadlines. During the Ebola response, novel contracting methods were used to support the development and evaluation of Ebola candidate vaccines and trials. While the federal government and the Department standard timeline for awarding contracts is 180 days, AMCG awarded the majority of its Ebola contract

actions within 60 days. All Project BioShield contract actions were awarded within 128 days starting at the end of FY 2014 and with the bulk of these actions in FY 2015. In FY 2015, 90 percent of ASPR's contract actions were completed, thereby ensuring that there is opportunity for businesses capable of meeting the needs of HHS to compete on a level playing field. Exceeding targets under the President's Small Business Initiative, ASPR awarded 51 percent of eligible contract dollars to small businesses, exceeding ASPR's 35 percent small business goal. Additionally in FY 2015, ASPR awarded 91 grants totaling $212,649,385.67.

**t. #30 – Incentivize development of rapid point-of-care diagnostics.**

ASPR/BARDA is funding the development of multiple rapid point-of-care diagnostics platforms; some are in the biothreat diagnostics space and some initially address other parts of ASPR/BARDA's mission. All platforms are applicable to the biothreat space with development of a threat specific assay. ASPR/BARDA's open CBRN solicitation contains "Areas of Interest" for development of rapid point-of-care diagnostics for all biothreats for which Material Threat Assessments have been issued. The PHEMCE Diagnostics Integrated Product Team is developing requirements for all of these biothreats. Some are already available and others are in process.

**u. #31 – Develop a 21st Century-worthy environmental detection system.**

This recommendation is best directed to DHS and DoD. HHS is not involved in the development of environmental detection systems.

**v. #32 – Review and overhaul the Select Agent Program.**

On October 29, 2015, the USG released two sets of recommendations, the Federal Experts Security Advisory Panel (http://www.phe.gov/s3/Documents/fesap.pdf) and the Fast Track Action Committee-Select Agent Regulations (http://www.phe.gov/s3/Documents/ftac-sar.pdf). Recommendations from both groups support efforts to enhance the Federal Select Agent Program. HHS co-chaired both these groups and is working with federal partners to improve biosafety and biosecurity practices based on these findings. The implementation plan (http://www.phe.gov/s3/Documents/fesap-ftac-ip.pdf) for these recommendations emphasizes culture of responsibility, strengthens oversight, promotes outreach and education, conducts applied biosafety research, develops an incident reporting system, enhances material accountability and inspection processes, and rulemaking to update current regulations and guidance.

3) **The Blue Ribbon Study Panel, GAO and other experts have recommended the development of a national biodefense strategy. To date, federal agencies have produced several strategic documents that address different aspects of biodefense, including the National Health Security Strategy and the National Biosurveillance Strategy. Do you believe that existing strategy and policy documents provide sufficient coordination of biodefense activities across the federal government? What elements should be included in a unified national strategy for biodefense?**

Various cross government strategies such as the National Health Security Strategy (NHSS), the National Biosurveillance Strategy, and the National Strategy for Countering Biological Threats collectively coordinate a strategic level direction for biodefense. Specific to ASPR, the NHSS is a robust strategy that addresses many components of biodefense: community health resilience; biosurveillance and situational awareness; medical and non-pharmaceutical countermeasures; health and public health and emergency management systems; and global capacity. It is an all-hazards strategy that addresses all emergencies that could impact human health. Enhancing national health security is a shared responsibility of all organizations (government and non-government), communities, and individuals.

**4) The Blue Ribbon Study Panel recommended the development of a unified budget for biodefense spending, and estimated that roughly $6 billion is spent every year on biodefense and related hazards. Please detail how much your Department or Agency spent on biodefense efforts (categorized by Threat Awareness, Prevention and Protection, Surveillance and Detection, and Response and Recovery activities, as defined by Homeland Security Presidential Directive 10) from Fiscal Years 2007-2016.**

Under Homeland Security Presidential Directive 10, the development, procurement, and stockpiling of MCMs, along with associated regulatory activities, are considered under the Response and Recovery mission. With that in mind, the PHEMCE coordinates federal efforts to enhance MCM preparedness for CBRN threats and emerging infectious disease. The PHEMCE is led by ASPR and includes primary HHS agency partners such as CDC, FDA, and NIH, as well as, several interagency partners such as DoD, the U.S. Department of Veterans Affairs, DHS, and USDA.

Within ASPR, BARDA is responsible for the advanced research and development and procurement of MCMs. BARDA’s appropriations are included in the table below for FY 2007 to FY 2016. The table does not include spending from the following three sources: 1) pandemic influenza supplemental funding bills passed in 2006, 2009, and 2010; 2) Special Reserve Fund appropriations in FY 2004 that supported Project BioShield through FY 2013; and 3) Ebola funding provided in either the FY 2015 continuing resolution or supplemental emergency funding provided in the FY 2015 omnibus appropriation. All BARDA funding included in the table would be categorized as Response and Recovery.

| Activity | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011* | FY 2012* | FY 2013* | FY 2014 | FY 2015 | FY 2016 |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** | **Enacted** |
| BARDA…….. | 119.741 | 131.419 | 306.052 | 340.531 | 340.531 | 340.531 | 415.000 | 778.165 | 734.906 | 1,086.691 |
| *Advanced Research and Development (ARD) (non-add)…….* | *119.741* | *131.419* | *306.052* | *340.531* | *340.531* | *340.531* | *415.000* | *413.494* | *415.000* | *511.700* |
| *Pandemic Influenza (non-add)**…………* | --- | --- | --- | --- | --- | --- | --- | *110.597* | *64.906* | *64.991* |
| *X-Year (non-add) …………..* | --- | --- | --- | --- | --- | --- | --- | *82.597* | *39.906* | *40.000* |
| *Annual (non-add) …………..* | --- | --- | --- | --- | --- | --- | --- | *28.000* | *25.000* | *24.991* |
| *Project BioShield (non-add) …………..* | --- | --- | --- | --- | | | | *254.074* | *255.00* | *510.00* |

*BARDA ARD was funded from a transfer from the Special Reserve Fund (SRF). The SRF is based on the initial appropriation of $5.6 billion for a ten-year period (FY 2004 to FY 2013) to support procurements under Project BioShield.
**Pandemic Influenza activities prior to FY 2014 were supported from supplemental balances provided to the Department in 2006, 2009, and 2010.

**5) Upon the release of the National Biosurveillance Strategy in July 2012, a strategic implementation plan for the strategy was slated for completion within 120 days. What is the status of the implementation plan? Please describe how the Office of the Assistant Secretary for Preparedness and Response coordinates biosurveillance programs and policy with other federal agencies, per the National Biosurveillance Strategy. If the implementation plan has been completed, please provide it to this Committee.**

ASPR serves on the NSC's Biosurveillance Sub-Interagency Policy Committee that coordinated development of the National Biosurveillance Strategy in July 2012. A draft Implementation Plan for the National Strategy for the Biosurveillance was developed in 2013; however, it was not released to the public.

**Senator Ron Johnson**

1) **In a letter from the Assistant Secretary for Preparedness and Response (ASPR) provided to me on June 12, 2015, the ASPR said that the Biological Incident Annex would be completed and approved in the Fall of 2015. Is that annex complete? If so, please provide a copy to the committee. If not, when will it be approved?**

The Federal Interagency Operational Plan Biological Incident Annex is not complete. The Federal Emergency Management Agency is responsible for the report.

2) **In a letter from the ASPR provided to me on June 12, 2015, the ASPR said that HHS was developing a formal report on its preparedness and response to the Ebola outbreak. Has this formal report been completed? If not, when will it be complete? If complete, please provide a copy to the Committee.**

The Department of Health and Human Services (HHS) released its formal report, *Report of the Independent Panel on the U.S. Department of Health and Human Services Ebola Response,* in June 2016. The report is available on the Office of the Assistant Secretary for Preparedness and Response's (ASPR) website at: http://www.phe.gov/Preparedness/responders/ebola/EbolaResponseReport/Pages/default.aspx.

3) **In a letter from the ASPR provided to me on June 12, 2015, the ASPR said that the HHS had not yet identified lessons related to the U.S.'s domestic preparedness and international response to the Ebola outbreak in 2014-2015. Has HHS identified any lessons learned and resulting corrective actions taken for its preparedness and response to the Ebola outbreak? If so, please identify such lessons learned and corrective actions.**

An independent panel of experts reviewed the Department's domestic and international response to the Ebola outbreak. The *Report of the Independent Panel on the U.S. Department of Health and Human Services Ebola Response* was released in June 2016. Within the report, the independent panel identified lessons learned and developed recommendations to improve HHS and United States Government (USG) leadership and coordination for future public health threats. In response to the independent panel's report, HHS released the *U.S. Department of Health and Human Services Ebola Response Improvement Plan* in June 2016, which describes the steps the Department will take to address the recommendations of the independent panel. The report is available on ASPR's website at: http://www.phe.gov/Preparedness/responders/ebola/Documents/EbolaIP.pdf.

4) **Has HHS completed an inventory of HHS' public health response capabilities and gaps in those capabilities? Please provide the comprehensive list of such capabilities and gaps. If HHS has not yet completed such an inventory, when will this process be completed?**

ASPR has the authority to deploy federal public health and medical personnel; directs the advanced research, development, and procurement of medical countermeasures; coordinates the integration of federal preparedness and response activities for public health emergencies; and

provides logistical support for the federal component of medical and public health responses. ASPR also supports building preparedness capabilities and resiliency at the community level before disasters or public health incidents occur. ASPR's flagship program in this regard, the Hospital Preparedness Program, has provided more than $5.1 billion to state and local health departments since 2002 to better prepare the nation's health care infrastructure for man-made or natural disasters.

ASPR has made numerous improvements to ensure national health security and to protect the American people. One such improvement is the development and continued refinement of the National Health Security Strategy (NHSS), which unified a patchwork of public health and medical preparedness, response, and recovery strategies. The NHSS works to ensure that the nation is prepared for, protected from, and resilient in the face of public health threats.

The NHSS established two overarching goals for national health security: 1) Build community resilience and 2) strengthen and sustain health and emergency response systems. With the National Health Security Review, ASPR emphasized capabilities and identified challenges for strengthening national health security, which informed the development of the National Health Security Strategy and Implementation Plan 2015-2018. Since the report, improvements have been made including:1) Integrating public health, health care, and emergency management systems; 2) Planning at the federal, state, and local levels; 3) Building national health security workforce capabilities; 4) Coordinating within government and between government and the private sector; and 5) Strengthening community resilience.

As a requirement of the Pandemic and All-Hazards Preparedness Reauthorization Act of 2013, HHS provided Congress with a Public Health & Medical Situational Awareness Strategy and Implementation Plan. This strategy and plan includes ways to development and expand the bio surveillance network; modernize and enhance biosurveillance activities; and improve information sharing, coordination, and communication among biosurveillance systems.

In addition, ASPR coordinates USG compliance for the U.S. International Health Regulations (IHR) (2005) National Focal Point and provides reports to the World Health Organization (WHO). ASPR currently leads USG participation in the WHO Joint External Evaluation Process, which assesses core competencies to prevent, detect, and respond to public health emergencies within the IHR framework and the Global Health Security Agenda.

**5) What process is HHS utilizing, together with other Departments and agencies, to identify major gaps in federal public health response and to prioritize capability development to meet such gaps?**

The Public Health and Emergency Medical Countermeasures Enterprise (PHEMCE) has two initiatives that assess federal MCM preparedness and response gaps and capabilities: 1) Preparedness Assessments; and, 2) Integrated Capability Documents (ICD).

The Preparedness Assessment for operational capacity compares the nation's current and projected five-year level of capacity against the need for new MCMs. The result is a prioritized list of initiatives to close preparedness gaps identified in the PHEMCE Strategy and

Implementation Plan. This snapshot allows senior leaders to prioritize PHEMCE resource allocations and strategically improve preparedness.

The ICDs describes core cross-threat capabilities (e.g., supplies, staff, space, and systems) for the medical and public health system. It also quantifies the current resource levels of these capabilities, lists potential non-material solutions to increase operational capacity, and projects current operational capacity based on potential constraining parameters (i.e., operational quantity).

This information allows senior leaders to consider national capabilities and better determine product-specific requirements, including the desired characteristics of each MCM class and how many MCMs should be stockpiled. This capabilities-based MCM planning delivers cost savings for certain MCM classes, makes assets available to acquire other critical MCMs, and improves confidence that stockpiled MCMs will be available for their intended use during a public health response.

**<u>Senator Claire McCaskill</u>**

1) **We had a hearing on Ebola in 2014, and I want to clear up a number of apparent discrepancies between the information my staff had received on medical countermeasures in the strategic national stockpile in response to a document request I made in November 2013 and information provided by Dr. Lurie in response to some questions for the record (QFR) that I submitted after that hearing.**

   **In a document request letter that I sent to the Department of Homeland Security (DHS) in November 2013, I requested a list of all Chemical, Biological, Radiological and Nuclear-related (CBRN) countermeasures procured for the strategic national stockpile between fiscal years 2004 and 2013. The information I received back from HHS had procurements for seven CBRN-related threats: radiation and nuclear exposure, anthrax, drug-resistant anthrax, botulism, smallpox, and nerve agents. Dr. Lurie's response to my QFRs indicates that HHS also holds countermeasures in the stockpile for cyanide, tularemia, plague, and typhus, and notes that acquisitions are planned to address exposure to glanders and research and development is ongoing for viral hemorrhagic fevers like Ebola.**

   **Please update the attached spreadsheet to reflect the additional procurements.**

The updated spreadsheet is attached:

BARDA Response 2
to QFRs to Hatchett f

Based on the Strategic National Stockpile (SNS) Annual Review Process and recommendations by the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE), the additional assets referenced by the Assistant Secretary for Preparedness and Response (ASPR) were acquired directly by the Centers for Disease Control and Prevention (CDC). The most recent inventory of SNS assets is available in the SNS Annual Review Report which was delivered to Congress in September 2015. The Department of Health and Human Services (HHS) is currently developing the 2015 SNS Annual Review Report FY 2018 Plan) which is anticipated by fall of 2016.

2) **When did the acquisition process begin for glanders, and where are you in that process?**

Product acquisition for glanders was initiated by the 2013 SNS Review process. As a result, the PHEMCE decided to procure meropenem IV for treatment, trimethoprim-sulfamethoxazole tablets for the longer term eradication phase, and a larger amount of trimethoprim-sulfamethoxazole tablets for post-exposure prophylaxis.

CDC is planning to procure meropenem and co-trimoxazole stockpiles for the treatment and post-exposure prophylaxis of glanders and melioidosis. Procurements that began in FY 2016 will be phased in through FY 2018.

3) **The information my staff received from HHS on countermeasure procurements listed 18 procurements that totaled over $3.3 billion. Yet in response to a question about the amount HHS was spending on medical countermeasures, Dr. Lurie stated that only 12 countermeasures had been procured under Project BioShield, plus an additional two procurements for so-called risk-mitigation products. Please explain the discrepancy between Dr. Lurie's statement and the 18 listed procurements on the attached spreadsheet?**

Procurements are broken out by contract. Notably, the VaxGen recombinant protective antigen anthrax vaccine procurement was terminated in December 2006 when VaxGen failed to meet a critical contractual milestone without delivering any doses to the SNS. In addition, because they represent different contracts, Cangene Anthrax Immune Globulin procurements of Raxibacumab (2005 and 2013) have been counted twice as separate procurements. Please note that Raxibacumab was initially a Human Genome Sciences contract in 2005, but was procured under a new contract with GlaxoSmithKline in 2013. As a risk mitigation strategy, HHS also procured the cell lines required to manufacture two other anthrax antitoxins (i.e., Valortim and AVP21D9) but has not procured these products. Finally, Emergent's BioThrax Anthrax vaccine has been procured twice under separate contracts (2005 and 2007).

4) **Dr. Lurie's QFR response also noted that generic antibiotics have been purchased for the Strategic National Stockpile to fulfil requirements for countermeasures against exposure to tularemia and plague. But those purchases weren't included in the information my staff received either. Did HHS negotiate lower prices for these generic antibiotics since they were bought in such high quantities?**

Please see the responses from Dr. Stephen Redd, who testified on behalf of CDC and is responding to this question on behalf of HHS agencies.

5) **Can you add those purchases to the enclosed spreadsheet?**

The attached spreadsheet only includes Project BioShield procurements using the Special Reserve Fund and does not include CDC procurements. However, the Pandemic and all-Hazards Preparedness Reauthorization Act of 2013 requires HHS to develop a five-year budget plan for the medical countermeasure enterprise, including CDC procurements and those made under the Special Reserve Fund. This multiyear plan is provided to the House and Senate Appropriations Committees each year and is used for strategic project coordination, product transitions between agencies, communication of priorities and resources to partner stakeholders, and assistance with long-term forecasting. The goal of the multiyear plan is to outline PHEMCE programmatic estimates on a five-year rolling basis and to identify the hand-offs in the development cycle in anticipatable budget terms. The current report covers PHEMCE spending estimates for FY 2015 through FY 2019.

**6) In the same response, Dr. Lurie noted that DHS has issued 13 Material Threat Determinations (MTDs) that are currently active. Yet the chart he provided shows 15 active MTDs. Can you explain this discrepancy?**

The chart depicted in Dr. Lurie's November 19, 2014 questions for the record lists each material threat assessment (MTA) individually. Four MTAs were combined into two Material Threat Determinations (MTD). Specifically, volatile and low volatile nerve agents have independent MTAs and both included as a single MTD issued in September 2011. Additionally, radiological materials and nuclear detonations have independent MTAs but are included as a single MTD issued in September 2004.

**7) I understand that we get non-exclusive licensing rights for patentable inventions that result from the development of medical countermeasures supported by the U.S. Government. Can you explain what this means, exactly?**

Under the Bayh-Dole Act (or Patent and Trademark Law Amendments Act) and its implementation, small businesses and nonprofit organizations that retain titles to inventions made and put into practice with federal support must grant the United States Government (USG) a nonexclusive, nontransferable, and irrevocable license. In other words, when the USG awards a grant, contract, or cooperative agreement to a small business or nonprofit organization for research and development of a MCM, the USG may use or license the invention to carry out USG purposes without paying a royalty to the small business or nonprofit organization.

**8) What is the federal government's threshold investment for obtaining licensing rights for a product that we've invested taxpayer dollars in?**

The licensing rights are determined in accordance with the Bayh-Dole Act and its implementation, which make no reference to a threshold investment.

**9) Have we retained licensing rights for any of the medical countermeasures in the strategic national stockpile, and, if so, which ones?**

The USG would retain a government use license for any invention initiated through federal investment, including products purchased for the SNS. Products purchased for the SNS might also be covered by privately owned inventions in which the government would have no rights.

**10) Have we used these rights and sold the license for any of these, and if so, how much have we made by licensing them? If not, why not?**

The Bayh-Dole Act government use license is a nontransferable license that cannot be sold or licensed to commercial parties to develop the invention. On the other hand, government-owned inventions are commonly licensed to commercial parties for commercialization under royalty bearing licenses by the agencies that developed the inventions.

**11) The strategic national stockpile has a large, but not unlimited, budget to purchase countermeasures in case of an attack or an outbreak of some kind. Yet we've spent $1.4 billion on anthrax countermeasures alone. Two of the investments were for anthrax antitoxins that cost $3,100 and $8,200 per dose. We also bought 10 million doses of Biothrax, an anthrax vaccine with a four-year shelf life, in 2005, and then we bought another 18.75 million doses two years later, which is two years before the shelf life of the first round of procurements. Can you explain the reasoning for the second round of purchasing?**

Anthrax is one of the more significant bioterrorism threats relative to other potential pathogens. Preparing for and responding to anthrax is a complicated process, which requires an array of medical products to:

1. Provide post-exposure antibiotic prophylaxis to individuals who may not be symptomatic, but have a likelihood of having been exposed. This ranges in the millions of possible doses for a 60-day course of treatment.
2. Provide vaccine for long-term protection to individuals who will be exposed to potentially contaminated environments and to augment protective coverage from antibiotics.
3. Provide antibiotics for treatment of actual anthrax disease.
4. Provide antitoxins for the treatment of anthrax toxemia (lethal toxin), a highly specific aspect of anthrax infection that is not addressed by administration of antibiotics.
5. Provide potential ventilatory support for patient management.

With that in mind and considering limited funding, the PHEMCE developed a strategy to target potential products based on greatest necessity. The idea was that once the nation's ability to counter anthrax improved, the PHEMCE would then address other areas of preparedness.

ASPR's Biomedical Advanced Research and Development Authority (BARDA) and the PHEMCE have made significant progress in preparing for the threat of an anthrax attack/release. BARDA has invested approximately $1.4 billion on anthrax antitoxins and anthrax vaccines. Current requirements for anthrax antitoxin include 288,000 treatment courses for anthrax and 526,000 treatment courses for multi-drug resistant anthrax. The current requirement for anthrax is enough vaccine to protect 25 million individuals. Considering that the current licensed regimen requires three doses, this equates to 75 million doses of anthrax vaccine.

**12) I understand that there are planned reductions in holdings of a number of products in the strategic national stockpile in order to meet projected budget appropriations and medical countermeasure preparedness will be affected for a more high-priority threats if current budgetary constraints continue. How are your funding priorities established, and how much is the anthrax investment crowding out other needed countermeasures?**

Annual review of the SNS (known as the SNS formulary) is mandated by Homeland Security Presidential Directive 21: Public Health and Medical Preparedness and Section 319F-2(a) of the Public Health Service Act. Through this review, the PHEMCE examines all SNS content, identifies and prioritizes formulary gaps, and recommends corrective actions to close those gaps.

The ultimate goal is to minimize the public health impact of events caused by high priority threats through the effective delivery of MCMs.

Recommendations are based on stockpiling goals established by the PHEMCE. The PHEMCE also considers various formulary options and recommends stockpile reductions in areas with minimal impact as possible impact on national MCM preparedness. In recent years, the amount of anthrax vaccine in the SNS has been reduced to allow for other critical acquisitions against anthrax and other high priority threats.

**13) I asked Dr. Lurie about how anthrax ended up in the strategic national stockpile because my staff received documents showing that this was not originally a priority for the strategic national stockpile, and in response, she stated that "It is a therapeutic that potentially could be effective against an antibiotic resistant anthrax infection and when present antibiotic therapy is not working." This answer sounds very theoretical to me. It "potentially could" be effective in the very specific situation where we have an antibiotic resistant anthrax infection AND when present antibiotic therapy isn't working.**

During the 2001 anthrax attacks, five of the 11 individuals who contracted inhalational anthrax died, even when treated with antibiotics. Antibiotics are only considered effective if initiated early in the course of disease. Anthrax antitoxins offer an improved treatment option to decrease overall mortality. If a drug resistant form of anthrax were used in an attack, the antibiotics would not be effective. However, the antitoxins, which were not available in 2001, would remain applicable. As mentioned previously, the PHEMCE strategy is to have antibiotics, antitoxins, and vaccines available to mitigate the negative health impacts of exposure or potential anthrax exposure.

**Do we know how or if anthrax works, and, if not, what is the reasoning behind using our limited funding on it for the strategic national stockpile when several other priorities have yet to be funded?**

Anthrax is an infectious and highly lethal disease that occurs when an infectious dose of anthrax spores reaches deep sites within the lung. Antibiotics and vaccines are known to be highly effective if administered very early after exposure. Anthrax antitoxins bind to one of the toxins produced by anthrax creating a protective antigen. Antibodies are generated against the toxin, meaning they reduce mortality. However, it takes time for the infected individual to generate antibodies after exposure. Often, even with antibiotic treatment, the generation of antibodies to the toxins takes too long. The administration of anthrax antitoxins provides for circulating antibodies that can bind to protective antigen, immediately, and reduce mortality. The U.S. Food and Drug Administration (FDA) has licensed/approved three anthrax antitoxins that have been evaluated in studies to show efficacy under the FDA animal rule. When antitoxins were evaluated in conjunction with an antibiotic in the animal models, they provided additional survival benefits compared to animals who received only antibiotics.

**14) Has there even been a Material Threat Assessment issued specifically for antibiotic resistant anthrax?**

A specific MTA for multidrug resistant anthrax does not exist. The multidrug resistant anthrax planning scenario and consequence modeling are a result of the broader April 2005 anthrax MTA.

**15) Imvamune hasn't been approved by the FDA, and Phase III trials aren't supposed to start until 2017. Yet we started adding it to the stockpile way back in 2007. The World Health Organization's Scientific Advisory Group of Experts noted in 2014 that Imvamune is not recommended for emergency use until more information is available regarding its efficacy and safety. In fact, one paper in the scientific journal Biosecurity and Bioterrorism stated unequivocally, "There is no apparent programmatic use for the vaccine at this time." What is the rationale for stockpiling something that the World Health Organization says should not be stockpiled?**

As you may know, ASPR was authorized by the Pandemic and All-Hazards Preparedness Act in December 2006. Within that authorizing language, ASPR was instructed to develop MCMs for the entire population, including at-risk populations. Imvamune was stockpiled in 2007 after the FDA determined that sufficient safety, efficacy, and manufacturing data existed to potentially use the vaccine under an Emergency Use Authorization (EUA) for individuals at risk for a serious adverse reaction to the licensed smallpox vaccine, ACAM2000, in the event that a public health emergency is declared. In particular, this pre-EUA includes individuals of all age groups with HIV and atopic dermatitis.

In June 2007, BARDA awarded a contract to Bavarian Nordic to manufacture Imvamune, a Modified Vaccinia Ankara (MVA) smallpox vaccine. The Imvamune vaccine was first delivered to the SNS in 2010 and was developed to augment, not replace, ACAM2000. Bavarian Nordic initiated its pivotal, Phase III safety and immunogenicity study in March 2015, which is designed to show non-inferiority to ACAM2000.

The World Health Organization's (WHO) Scientific Advisory Group provided recommendations, but the WHO actually requested that a portion of the smallpox vaccine stockpile include Imvamune.

**Senator Rob Portman**

1) **In your testimony you mention the coordinating bodies at work during crises—specifically the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) and the Disaster Leadership Group (DLG)—whose role it is to coordinate and collaborate with a broad range of stakeholders and agencies during emergencies. While you mention the PHEMCE initiated an early response to Ebola, I think many of us also remember the many systematic problems that led to an uncoordinated and slow response to Ebola.**

   **Based on your role as Acting BARDA Director and Acting Deputy Assistant Secretary at ASPR and the involvement in the Ebola response, what were the major lessons learned for your agency? How have you worked to address any lack of coordination and improve on the agency's response for the future?**

In June 2016, the Department of Health and Human Services (HHS) released a formal report titled *Report of the Independent Panel on the U.S. Department of Health and Human Services Ebola Response*. Within the report, an independent panel identified lessons learned and developed recommendations to improve HHS and United States Government (USG) leadership and coordination for future public health threats. The report can be found at: http://www.phe.gov/Preparedness/responders/ebola/EbolaResponseReport/Pages/default.aspx.

In response to the independent panel's report, HHS released the *U.S. Department of Health and Human Services Ebola Response Improvement Plan* in June 2016, which describes the steps the Department will take to address the recommendations of the independent panel. The report is available on ASPR's website at: http://www.phe.gov/Preparedness/responders/ebola/Documents/EbolaIP.pdf.

2) **While I understand Zika is different from the Ebola epidemic we faced in 2014, I think we would benefit from applying lessons learned during the rapid spread of Ebola in 2014. In 2014, Congress appropriated $5.4 billion in emergency funding to combat Ebola, specifically by providing funding to the FDA and the Biomedical Advanced Research Development Authority to support the development of rapid diagnostics and treatments. I think Zika provides us with an opportunity to test these new mechanisms and utilize this new infrastructure to address Zika more rapidly than Ebola.**

   **GAO has previously recommended that since the mission responsibilities and resources for biosurveillance are dispersed across a number of federal agencies, efforts to develop a biosurveillance system could benefit from focused leadership for the interagency community. The Blue Ribbon Study Panel on Biodefense Report also highlighted that U.S. biodefense programs lack of clear governance structure and leadership.**

   **What is your agency doing to address these recommendations? How did the lack of focused leadership impact the initial Ebola response? What improvements can be made as we approach the U.S. response to Zika?**

As the principle advisor to the Secretary on matters relating to federal public health and medical preparedness in response to public health emergencies, ASPR is consistently working on ways to improve biodefence coordination through structures such as the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) and the Disaster Leadership Group (DLG). Through the PHEMCE ASPR leads engagement with key leadership across HHS to share information and coordinate preparedness and response activities. Likewise, ASPR leads the DLG, which is a medium for interagency partners to discuss and combine resources that produce MCMs for identified and suspected bio threats. Both the DLG and PHEMCE are working effectively to coordinate efforts across the Department and interagency.

With that in mind, ASPR does not manage biosurveillance programs. However, ASPR is a consumer of biosurveillance information which helps to direct PHEMCE priorities.

| Contract Number | Brand and Generic Name of Countermeasure Procured | Type of Countermeasure (Purpose and Target Population) | Purpose (of Countermeasure) | Target Population (of Countermeasure) |
|---|---|---|---|---|
| HHSO100200500002C | Potassium Iodide (Thyroshield) | radiological-nuclear decorporation agent | treatment of individuals exposed to radiation | Pediatric including infants. Thyroshield is the liquid formulation of potassium iodide. |
| HHSO100200600019C | BioThrax (AVA- Anthrax Vaccine Absorbed) | anthrax vaccine | prevention of anthrax | Post-exposure treatment of adults exposed to anthrax. |
| HHSO100200500007C | Anthrax Immune Globulin Intravenous-AIG | anthrax antitoxin(Polyclonal antibody) | used to treat anthrax | Pre-EUA for treatment of adults. Pediatric dosing recommendations available. **Product is now licensed for treatment of anthrax.** |
| HHSO100200500006C | ABthrax (Raxibacumab) | anthrax antitoxin (monoclonal antibody) | used to treat anthrax | Approved for use in adults for treatment of inhalational anthrax due to Bacillus anthracis in combination with appropriate antibacterial drugs and for post-exposure prophylaxis when alternative therapies are not available or are not appropriate. Product is labeled for use in all relevant pediatric populations. |
| HHSO100200500008C | IV Calcium/Zinc DTPA (Diethylene triamine pentaacetic acid) | radiological-nuclear decorporation agent | treatment of individuals exposed to radiation | Approved for use in adults. Pediatric and infant dosing recommendations available |
| HHSO100200600017C | hBAT | Botulinum Antitoxin (BAT) Therapeutic | used to treat exposure to botulism | Licensed for the treatment of symptomatic botulism following documented or suspected exposure to botulinum neurotoxin serotypes A, B, C, D, E, F, or G in adults and pediatric patients |
| HHSO100200500001C | rPA (Recombinant Protective Antigen) | anthrax vaccine | prevention of anthrax | Not applicable…contract close out WE HAVE ACTUALLY BOUGHT THIS PRODUCT AND IT IS NOW LICENSED. NEED it updated below. |
| HHSO100200700034C | Imvamune (MVA-Modified Vaccinia Ankara) | smallpox vaccine | prevention of smallpox | Available for potential use during a declared emergency under EUA for individuals with HIV or atopic dermatitis to include all age ranges and nursing and pregnant women |
| HHSO100200700037C | BioThrax (AVA- Anthrax Vaccine Absorbed) | anthrax vaccine | prevention of anthrax | Post-exposure prophylaxis of adults exposed to anthrax. **Vaccine is now licensed for Post-exposure prophylaxis (PEP)** |
| HHSO100201100001C | ST-246 | smallpox antiviral | treatment of symptomatic smallpox | Adults. Note: product has been used under CDC-IND in pediatric; pediatric dosing recommendation may be available. |
| HHSO100201300006I | Neupogen (G-CSF cytokine) | Anti-Neutropenia Cytokines for ARS | treatment of neutropenia in the event of a nuclear detonation | Neupogen (filgrastim, Amgen Inc.) may be effective in increasing survival by decreasing the risk for serious infections in humans exposed to myelosuppressive radiation following a radiological/nuclear incident. **Product is now approved by the FDA for treatment of ARS in adults and pediatrics** |
| HHSO100201300009I | AIG | Anthrax Antitoxin | used to treat anthrax | This program is for the collection of plasma only. Plasma will be stored until current product in the SNS begins to expire |
| HHSO100201300012I | Valoritim | Anthrax Antitoxin | NA(cell bank only) | Not applicable. BARDA purchased the cell bank as a risk mitigation strategy |
| HHSO100201300008I | Raxibacumab | Anthrax Antitoxin | used to treat anthrax | Approved for use in adults for treatment of inhalational anthrax due to Bacillus anthracis in combination with appropriate antibacterial drugs and for post-exposure prophylaxis when alternative therapies are not available or are not appropriate. Product is labeled for use in all relevant pediatric populations. |
| HHSO100201300010I | ETI-204 | Anthrax Antitoxin | Not applicable | Not applicable |
| HHSO100201300011I | AVP21D9 | Anthrax Antitoxin | Not applicable | Not applicable. BARDA purchased the cell line as a risk mitigation strategy |

| Contract Dates | Contractor Name | Data Universal Numbering System (DUNS) Number | Total Funds Obligated to Date | Total Contract Value | Contract Type | Limited Competition or Sole-Source |
|---|---|---|---|---|---|---|
| 3/17/2005 | Fleming | 006491351 | $17,629,003 | $18 M | Firm Fixed Price | Full and Open Competition |
| 5/1/2005 | Emergent | 189488554 | $242,737,000 | $243 M | Fixed Price | Only One Source - Other (FAR 6.302-1 other)[1] |
| 9/1/2005 | Cangene | 253134134 | $160,424,719 | $160 M | Cost Reimbursement and Fixed Price | Full and Open Competition |
| 9/1/2005 | Human Genome Sciences | 797057437 | $339,414,352 | $334 M | Firm Fixed Price and Cost Reimbursement | Full and Open Competition |
| 12/1/2005 | Akorn | 62649876 | $21,962,448 | $22 M | Firm Fixed Price | Only One Source - Other (FAR 6.302-1 other)[1] |
| 9/1/2006 | Cangene | 253134134 | $465,528,871 | $462 M | Firm Fixed Price and Cost Reimbursement | Full and Open Competition |
| 12/1/2006 | VaxGen | 6899173 | $1,534,253 | $ 2 M | Firm Fixed Price - IDIQ | Full and Open Competition |
| June 2007, Sept.2011 | Bavarian Nordic | 310209754 | $659,154,526 | $541 M, $110M | FFP | Full and Open Competition |
| 9/1/2007 | Emergent | 26489018 | $456,305,000 | $456 M | Firm Fixed Price | Only One Source - Other (FAR 6.302-1 other)[1] |
| 5/13/2011 | SIGA | 932651516 | $432,885,825 | $433 M | FFP/CPFF | limited competition[2] |
| 9/1/2013 | Amgen | 962075045 | $157,692,386 | $158 M | Firm Fixed Price | Full and Open Competition |
| 9/1/2013 | Cangene | 244844056 | $63,404,735 | $ 63 M | IDIQ | Full and Open Competition |
| 9/1/2013 | PharmAthene | 082804936 | $1,079,538 | $1 M | IDIQ | Full and Open Competition |
| 9/1/2013 | GlaxoSmithKline | 167380711 | $196,832,500 | $ 197 M | IDIQ | Full and Open Competition |
| 9/1/2013 | Elusys | 83819511 | $44,951,100 | $0.00 | IDIQ | Full and Open Competition |
| 9/1/2013 | Emergent | 189488554 | $453,092 | $0.00 | IDIQ | Full and Open Competition |

| Number of Doses Procured | Cost Per Dose | Expiration Date of Countermeasure | Approved by the Food and Drug Administration (FDA)? | Intended for Strategic National Stockpile? | Emergency Use Authorization (EUA)? |
|---|---|---|---|---|---|
| 4.8 million doses | The USG paid approximately $3.70 per dose | | yes | yes | Approved by the FDA |
| 10 million doses [original contract for 5 million doses; option exercised for additional 5 million doses] | $24.27 per dose of vaccine | 4yr Expiry | Yes, for General use prophylaxis but NOT for post-exposure prophylaxis | yes | Yes (for post exposure prophylaxis) |
| 10,000 doses, deliveries completed | The USG paid approximately $8200 per dose for AIG. The remaining funds were associated with late stage development activities to support licensure of the product | Not yet licensed so there is no associated expiry | No | yes | Yes |
| 65,000 doses, deliveries complete | The USG paid approximately $3100 per dose for Raxibacumab. The remaining funds were associated with late stage development activities to support approval of the product | 5yr Expiry | yes | yes | Approved by the FDA |
| 473,710 doses | | | yes | yes | Approved by the FDA |
| 144,256/200,000 doses delivered | The USG paid approximately $1200 per dose for HBAT. The remaining funds were associated with activities to support licensure of the product and to maintain the large horse herd; plasma is derived from horses. | 4yr Expiry | yes | yes | Licensed by FDA |
| 0 | Not applicable | N/A | | | |
| 20million / 20 million doses delivered; 288,000/4 million | The USG paid approximately $18.25 per dose for the vaccine. The remaining funds are associated with activities to support licensure of the product | Not yet licensed so there is no assigned expiry. Data to support 3yr expiry as required by contract | No | yes | Yes |
| 18.75 million doses | The USG paid approximately $22.50 per dose of vaccine. The remaining funds were associated with activities to support licensure for Post-exposure prophylaxis | 4yr Expiry | Yes, for General use prophylaxis but NOT for post exposure prophylaxis | yes | Yes for post exposure prophylaxis |
| 0.920/1.7 million | The USG paid approximately $241 per treatment course. The remaining funds were associated with activities to support approval of the product. | Not yet approved so no assigned expiry. Has to meet 56 month expiry based on contract | No | yes | CDC held IND and pre_EUA package |
| 35,203 treatment courses | 270,538 prefilled syringes $22.83 per syringe, 270,538 vials at $273.89 per vial. Remaining funds support the fee associated with vendor managed inventory. | The product is maintained under vendor managed inventory so does not expire since it is rotated through the commercial market if not needed by the USG | approved to treat neutropenia associated with myelosuppressive therapy for cancer | no; vendor managed inventory (VMI) | EUA for neutropenia resulting for exposure to ionizing radiation |
| 10,000 dose equivalents of plasma | Not applicable because the plasma will be stored as plasma and there will be a future cost associated with manufacturing the product to replace doses currently in the SNS that will expire | N/A | N/A | yes | N/A |
| cell bank | Not applicable | N/A | N/A | N/A | N/A |
| 60,000 doses to be delivered | $3,280 per dose | 5yr Expiry | yes | yes | Approved by the FDA |
| 0 | not applicable | N/A | N/A | N/A | N/A |
| cell bank | not applicable | N/A | N/A | N/A | N/A |

| Multi-Agent Use or Commercial Application | Date of Material Threat Determination | Notes | For PBS procurement, did the contractor receive BARDA funds for development? | If so, date(s) of development funding: | Funding Amount (s): |
|---|---|---|---|---|---|
| no | September 23, 2004 | | No | | |
| No | January 20, 2004 | | No | | |
| no | January 20, 2004 | | yes | FY2005-2016 | $70,400,000 |
| No | January 20, 2004 | | Yes | FY2005-2013 | $28,000,000 |
| no | September 23, 2004 | | Yes | FY 2011, FY 2012, FY 2013 | $300,000 |
| public health compassionate use | June 14, 2004 | | yes | 2006-2014 | $62,800,000 |
| | January 20, 2004 | | Yes* | FY 2007 | $2,420,000 |
| No, not specifically. However the MVA vector is being developed for commercial applications. | MTD 2004 | | Yes | FY 2011 | $7,800,000 |
| No | January 20, 2004 | | No | | |
| no | | MTD 2004 | Yes | FY 2011, FY 2013 | $30,500,000 |
| Yes, there is a commercial market for this product | September 23, 2004 | | | | |
| yes | January 20, 2004 | The developed product comes from a prior Cangene contract HHSO100200500007C | Yes | 9/23/2005-4/30/2021 | $160,848,139 |
| N/A | January 20, 2004 | | No | | |
| No | January 20, 2004 | The developed product comes from a prior HGS contract HHSO100200500006C | Yes | 9/23/05-3/31/14 | $359,232,456 |
| N/A | January 20, 2004 | | No | | |
| N/A | January 20, 2004 | | No | | |

| | | | | |
|---|---|---|---|---|
| HHSO100201300005I | Leukine (GM-CSF cytokine ) | Anti-Neutropenia Cytokines for ARS | treatment of neutropenia in the event of a nuclear detonation | -Approved to treat shorten time to neutrophil recovery following chemotherapy.<br>-Pre-EUA package submitted for radiation induced neutropenia.<br>-Safety and effectiveness in pediatric patients not established; however, available safety data indicate that Leukine does not exhibit any greater toxicity in pediatric patients than in adults. Not recommended for neonates. |
| HHSO100201300024C | Midazolam | Chemical Antidote | treatment of individuals exposed to chemical nerve agents | Adults and pediatrics for status epilepticus and seizures associated with exposure to chemical nerve agents |
| HHSO100201500012C | hBAT | Botulinum Antitoxin (BAT) Therapeutic | Horse Herd Maintenance | Supports maintenance of the hyper immune horse herd. Bot antibodies are generated from horse plasma. |
| HHSO100201500035C | NexoBrid | Burn | Enzymatic Debridement | Technology to decrease mechanical debridement of burn wounds and increase potential outcome of burn patients |
| HHSO100201500028C | ReCell | Burn | Autograft Sparing | Technology to decrease the volume of autograft tissue that is needed to cover a burn wound and reduce the associated pain and potential infection that is associated with donor tissue site harvesting. |
| HHSO100201500027C | Stratagraft | Burn | Artificial Skin Substitute | A cell-based skin substitute that reduces the necessity for harvesting of donor tissue |
| N/A | Silverlon | Burn | Burn Bandages | A field dressing that can be applied to burn wounds, removed and reapplied without complications of the current burn gels. |

[1] Only one vendor was able to provide the medical countermeasure product (See Project BioShield Reports 2005 - 2008).

[2] Limited competition was available for the medical countermeasure product due to the product specifications, regulatory requirements, and product availability in the given timeframe (See Project BioShield Reports 2011).

| | | | | | | |
|---|---|---|---|---|---|---|
| 9/1/2013 | Sanofi-Aventis | 824676584 | $36,843,339 | $ 37 M | IDIQ | Full and Open Competition |
| 9/1/2013 | Meridian Medical Technologies | 49504624 | $60,790,629 | $60,790,629.05 | CPFF and FFP CLIN's | Full and Open Competition |
| 6/1/2015 | Auburn University | | $7,000,000 | | | |
| 9/1/2015 | Mediwound | | $40,430,469 | | | |
| 9/1/2015 | Avita Medical | | $16,901,424 | | | |
| 9/1/2015 | Stratatech | | $59,998,027 | | | |
| 9/1/2015 | DoD/DLA | | $19,999,989 | | Interagency Agreement | |
| | | | $3,359,623,316 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 4,340 treatment regimens | 66,700 vials at $198.74 per vial. The remaining funds are associated with studies to support approval of the product for neutropenia resulting from exposure to ionizing radiation (ARS) | The product is maintained under vendor managed inventory so does not expire since it is rotated through the commercial market if not needed by the USG | approved to treat neutropenia associated with myelosuppressive therapy for cancer | no; vendor managed inventory (VMI) | BARDA is providing support for additional studies that may be necessary to support emergency use for neutropenia resulting from exposure to ionizing radiation and to support the approval for this indication |
| 0/2.3 million doses | Adult Autoinjectors 653,100 $28.88 per autoinjector, pediatric autoinjectors 123,350 $32.68 per autoinjector, 675,375 multi dose vials to make up remainder of 2.3M doses at a cost of $6.88 per vial. Remaining funds are associated with activities to support approval for adults and pediatrics for status epilepticus and seizures associated with exposure to chemical nerve agents. | 3yr expiry | approval for preoperative sedation/anxiolsis/amnesia | yes; ChemPACK replenishment | Possibly. Working with PHEMCE partners to include DOD and NIH |
| N/A | | | | | |
| | | | | Yes | |
| | | | | Yes | |
| | | | | Yes | |
| 30,422 bandages | | | | Yes | |

| | | | | | |
|---|---|---|---|---|---|
| Yes, there is a commercial market for this product | September 23, 2004 | | | | |
| yes | September 28, 2011 | | | | |
| | | | | | |
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| | | | | | |
| | | | | | |

$722,300,595

**Dr. Stephen Redd**
**Centers for Disease Control and Prevention**
**Responses to Questions for the Record**
**Senate Homeland Security and Government Affairs Committee**
**"Federal Perspective on the State of Our Nation's Biodefense"**
**April 14, 2016**

**Senator Kelly Ayotte:**

**1. On April 13, the Centers for Disease Control and Prevention announced that there is now definitive evidence that the Zika virus causes microcephaly and other serious brain defects in infants. The CDC also estimated that up to 30 percent of women in infested areas may eventually contract Zika. Our neighbors in Puerto Rico have already been severely impacted by the virus. There have been travel-associated cases of Zika in my home state of New Hampshire.**

> **a. How is the CDC coordinating with other relevant federal agencies, as well as state departments of health and health departments in Puerto Rico, the U.S. Virgin Islands, and American Samoa in the fight against Zika?**

CDC's State Coordination Task Force, one of several CDC Zika response incident management teams, works very closely with state and territorial public health departments, including those in Puerto Rico, U.S. Virgin Islands, and American Samoa. CDC deployed senior epidemiologists and other subject matter experts to these territories to help manage the local response. In addition, the State Coordination Task Force established desks with dedicated staff who are in daily contact with CDC and local health department staff to provide technical assistance and to coordinate responses to requests for information and resources. CDC also works closely with the territories to help them develop Zika response plans and funded a $6.5 million contract to provide dedicated Zika response staff to the Puerto Rico Department of Health and other territories to ensure continuity of response operations.

Many of the CDC Zika response activities currently underway support state, local, tribal, and territorial health department response activities. Examples of these activities include:

- Improving laboratory testing surge capacity
- Deploying CDC staff to affected areas
- Providing vector control guidance and services
- Conducting maternal health surveillance and outreach, including implementation of a U.S. pregnancy registry
- Providing risk communications materials
- Developing Zika prevention recommendations

CDC planning guidance for states, territories, and localities include:

- Guidance on a risk-based plan that includes actions to be considered upon laboratory confirmation of the first locally acquired case of Zika virus infection in their jurisdiction and a support tool for them to consider a phased response to Zika virus.
- Guidance for vector control that accompanies the phased risk-based plan.
- Resources for risk communication.

On April 1, 2016 CDC hosted a Zika Action Plan (ZAP) Summit to:

- Provide senior state and local officials with information and tools needed to improve Zika preparedness and response within their jurisdictions.
- Increase knowledge on the latest Zika science, including implications for pregnant women.
- Increase knowledge of crisis and risk communication principles.
- Accelerate readiness for local response to Zika transmission through training and technical assistance to help jurisdictions establish surveillance and identify best practices for vector control.

During the ZAP Summit, CDC obtained feedback from participants on challenges and issues that required follow-up. Based on that feedback, CDC initiated a series of teleconferences in 2016 to provide updates on key areas of interest. They include:

- Communications: May 6
- Pregnancy and Birth Defects: May 11
- Vector Surveillance/Control: May 17
- Sexual Transmission/Pregnancy Planning: June 2
- Epidemiology: June 8
- Diagnostics/Laboratory Capacity/Testing Interpretation: June 13

CDC announced availability of funds to accelerate state and local Zika response planning.

- Public Health Preparedness and Response (PHPR) Cooperative Agreement for All-Hazards Public Health Emergencies ($25 million):
  - 41 state, 4 locality, and 8 territorial applicants. Eligibility is based on the geographic locations of the two mosquitoes known to transmit the Zika virus (*Aedes aegypti* and *Aedes albopictus*).
  - Supports building specific capabilities such as to respond to Zika virus disease, to reduce the spread of Zika associated with *A. aegypti* and *A. albopictus* mosquitoes, and to minimize maternal-fetal transmission of Zika virus.
- Epidemiology and Laboratory Capacity for Infectious Diseases funding:
  - Zika epidemiology and laboratory testing ($39 million) and Zika vector control and surveillance ($15 million).
- U.S. Zika Pregnancy Registry. Total funding amount of approximately $8.5 million.

Examples of how CDC is coordinating with other federal agencies are noted in responses to sub-questions (b) and (c) below.

**b. Has there been a formal plan developed that is comprehensive in nature and that focuses on interagency coordination at the state and federal levels, prevention, and response?**

Yes. CDC actively participated in the development of an HHS Zika response plan (United States Department of Health and Human Services Zika Virus Disease Preparedness and Response Plan for Areas at Risk for Local Zika Virus Transmission and High-Volume of Travel Associated Cases), and response plans for Puerto Rico and other affected territories.

CDC also provided guidance for states and localities to develop plans that includes a phased response comprising four categories of risk:

1. preparation (vector present or possible in jurisdiction)

2. mosquito season (*A. aegypti* or *A. albopictus* mosquito-biting activity)
3. confirmed local transmission (single case, or cases clustered in a single household/community in a county or jurisdiction)
4. widespread local transmission (multiple locations within a county/jurisdiction).

Each risk category includes recommended response activities in the following targeted areas: response action, communication, surveillance, laboratory testing, vector control, outreach to pregnant women, and blood safety.

CDC also provided guidance to state, tribal, local and territorial jurisdictions to conduct response exercises. CDC recommends that all 50 states, Puerto Rico, the U.S. Virgin Islands, and U.S. Affiliated Pacific Islands exercise portions of their Zika Action Plans as the ongoing outbreak necessitates.

c. **If so, could you provide details that demonstrate how these agencies are working together?**

CDC is collaborating with multiple agencies on the Zika response. These activities include:

- Vector control:
  - Environmental Protection Agency (EPA) provided emergency use permits for In2Care mosquito traps, which include an insecticide that attracts mosquitoes that transmit Zika virus and LifeNet bed nets. Section 18 permits are also pending for other mosquito control products.
  - Department of Transportation (DOT) and the EPA on disinfection recommendations for aircraft.
  - Department of Defense (DoD) on providing training to mosquito control application teams.
  - Navy Entomology Center of Excellence to identify novel mosquito products and application technologies which could be utilized to control Zika outbreaks.
  - DoD to assess the presence of the mosquito vector in the Republic of the Marshall Islands (RMI) and the ability of RMI to control the vector.
- International:
  - The United States Agency for International Development (USAID) is transferring $78M to CDC for the Zika response; CDC is working closely with USAID to identify projects for these resources.
- Blood safety:
  - CDC has been working closely with state, local, and territorial health departments, the U.S. Food and Drug Administration (FDA), the Biomedical Advanced Research and Development Authority (BARDA), public health partners such as the Council of State and Territorial Epidemiologists, and blood collection organizations to ensure a safe and sustainable U.S. blood supply. These efforts include providing guidance on implementing FDA recommendations for donor deferral, donor screening, and product management to reduce the risk of transfusion-transmission of Zika virus.
- Research:
  - National Institutes of Health (NIH) to facilitate the transfer of research efforts into products and services that will effectively combat Zika.
- Puerto Rico collaboration:
  - CDC linked the Puerto Rico Housing Authority (part of the U.S. Department of Housing and Urban Development) to partners, including Home Depot, to explore methods and strategies to mosquito-proof homes.

- Diagnostics:
  - BARDA to expand laboratory diagnostics manufacturing in the short-term and encourage commercial production of the immunoglobulin (IgM) assay in the long-term.

**2. About a month ago, Senator Burr and I wrote to FDA to urge the agency use its authority to place Zika virus on the FDA's Priority Review Voucher program list of qualifying Neglected Tropical Diseases. Such a designation would help accelerate much needed research on Zika and even potentially lead to a Zika vaccine or treatment by leveraging private investment. In 2014, I cosponsored a bill that was signed into law which placed Ebola on the same priority review list.**

**In their response to our letter, the FDA noted that it did not believe the Zika virus met the criteria for the Priority Review Voucher program because there "appears to be a significant market for Zika virus medical products in developed nations" thereby making Zika ineligible for the program. I was disappointed in this response.**

**a. Do you disagree with the FDA's finding that Zika would not be a good candidate for its Priority Review Voucher program?**

S. 2512, signed into law on April 19, 2016, adds the Zika Virus to the list of tropical diseases included under the FDA Priority Review Voucher Program.

**b. Can you put into context the threat that Zika poses versus our current ability to mitigate the spread of the virus?**

Zika virus is transmitted primarily through the bite of an infected *Aedes* species mosquito (*A. aegypti* and *A. albopictus*). These are the same mosquitoes that spread dengue and chikungunya viruses. Forty-one states have the type of mosquitoes that can become infected with and spread Zika virus.

Predicting the degree of any local transmission is difficult as many different ecological, environmental, and human factors influence the likelihood of any transmission. Some of these factors include the time of year, weather patterns, population density, type of housing, penetrance of air conditioning or screens, presence of vector breeding sites, and human behavior. These factors influence the number of mosquito vectors around an infected person and the likelihood of the vector biting another person. Experience with local transmission of dengue and chikungunya, other *Aedes*-transmitted viruses, in the continental United States in recent years might be predictive; in all cases, when local transmission occurred, it was of limited duration and affected few people. While dengue and chikungunya diseases provide a predictive model, and suggest that any outbreaks in the U.S. mainland are likely to be relatively small and localized, we cannot predict the extent of any local transmission of Zika virus with complete confidence due to the variety of factors that can influence transmission.

CDC continues to work at the highest level of response along with state, local, and territorial health officials to understand the risks Zika virus poses to people and quickly share what we learn. The agency collaborates with public health partners and with state health departments to alert healthcare providers and the public about Zika, to provide state health laboratories with diagnostic tests, to publish guidelines for testing of people with suspected Zika, and to publish guidance documents for response planning.

**c. Shouldn't that be a key component when considering ways to expedite the ability to produce a safe and effective vaccine or an improved diagnostic test?**

Yes, since the beginning of the Zika response, CDC received Emergency Use Authorizations (EUAs) from FDA for two new diagnostic tests for Zika virus. The CDC Zika IgM Antibody Capture Enzyme-Linked Immunosorbent Assay (Zika MAC-ELISA) detects antibodies that the body makes to fight a Zika virus infection. The test is used on blood samples from people with a history of symptoms associated with Zika and/or people who have recently traveled to an area during a time of active Zika transmission. The Trioplex Real-time (RT)-PCR Assay allows doctors to tell if an individual is currently infected with chikungunya, dengue, or Zika using one test, instead of having to perform three separate tests. As of June 6, 2016, 38 laboratories (in 32 states including District of Columbia (DC), 3 DoD laboratories) have completed verification panels for the Zika MAC-ELISA test. Seventy-four laboratories including 15 DoD laboratories in 39 states and DC and Puerto Rico have completed verification panels for the Trioplex test. These diagnostic tools were developed by CDC and granted EUAs earlier this year.

CDC is building laboratory capacity and infrastructure to test for Zika virus and other infectious diseases across the U.S. by providing critical laboratory supplies, reagents, equipment, and training for diagnostic testing and surveillance activities in states and territories. CDC resources are supporting laboratory surge capacity, which will help meet state testing needs, especially in Puerto Rico. In addition, CDC continues to work on improving diagnostics for Zika.

In preparation for a possible increase in demand, additional CDC laboratories have been trained and equipped to accept specimens for Zika testing. CDC can respond to an increase in demand and expand capacity through training additional staff at CDC and within state and local health departments via the Laboratory Response Network (LRN). CDC also partners closely with the Association of Public Health Laboratories (APHL), which can assist with expansion of laboratory capacity. Availability of a commercial manufacturer of the diagnostic tools would also assist with capacity.

**Senator Tammy Baldwin:**

**Dr. Redd, thank you for CDC's ongoing work to investigate and respond to the recent and concerning outbreak of Elizabethkingia anophelis in Wisconsin.**

1. **How is CDC supporting the Wisconsin Department of Health Services' disease preparedness and response efforts and capabilities during this Elizabethkingia investigation?**

CDC provides support to Wisconsin through multiple funding awards to help support the state's response to infectious disease outbreaks. In Fiscal Year (FY) 2015, Wisconsin received $3,028,480 from CDC through the Epidemiology and Laboratory Capacity for Infectious Diseases (ELC) cooperative agreement. This funding supports outbreak investigations through expanded epidemiology and laboratory capacity, including cross-cutting epidemiology and laboratory staff. CDC also provided Wisconsin $10,844,792 in FY 2016 through the Public Health Emergency Preparedness (PHEP) cooperative agreement. This program funds state, local, and territorial health departments to improve readiness to respond to public health emergencies.

Beyond funding, a CDC Epidemic Intelligence Officer assigned to and stationed in Wisconsin was integral to the initial *Elizabethkingia* investigation. A total of 19 CDC investigators were deployed to Wisconsin to provide onsite technical assistance to the Wisconsin Department of Public Health (WDPH) from February 14, 2016 (the date of the hearing) through April 17, 2016. More than 70 epidemiologists, laboratory staff, and leadership in CDC's Division of Healthcare Quality Promotion; Division of High-

Consequence Pathogens and Pathology; and Division of Foodborne, Waterborne, and Environmental Diseases at CDC Headquarters in Atlanta are providing substantial support.

The joint CDC-WDPH investigation eventually identified 66 cases of primarily community-associated infections, all occurring in southeastern Wisconsin, northeastern Illinois, or western Michigan, with specimen collection dates from November 23, 2015 to May 30, 2016. CDC assisted in patient interviews and clinical data review to identify potential patient exposures, conducted point prevalence surveillance of patients and contacts, environmental sampling, and provided laboratory testing and technical assistance for patient and environmental isolates. The patients have a variety of healthcare and community exposures and co-morbidities. Hypothesis generating interviews, structured interviews, and environmental sampling did not identify a food, water source, personal care product, healthcare product, or healthcare setting as a point source.

CDC recently deployed additional investigators to Wisconsin on July 18, 2016 in a further attempt to identify an organism source. CDC investigators will assist WDPH to identify common exposures through patient focus group interviews with small groups of patients with related isolates. CDC and WDPH will then apply the findings from the patient focus group interviews to identify prevention and control measures.

2. **How is CDC assisting Wisconsin's public health laboratories in this investigation, including working to identify a source of the outbreak and the rapid testing of Elizabethkingia samples?**

CDC work on the *Elizabethkinga* outbreak includes genetic and microbiological testing and analysis, determining growth characteristics, and creating specialized selection media for isolation. Informatics specialists, epidemiologists, and academic partners have tested samples for antibiotic resistance, performed genome sequencing, and conducted multiple analyses to shed light on the source of this outbreak. CDC is also developing new screening tools, such as an *Elizabethkingia* specific Real-time polymerase chain reaction (RT-PCR), which is now able to help screen samples.

CDC continues to work closely with investigators in Wisconsin and Illinois in the continuing investigation and in identifying the source of *Elizabethkingia anophelis* (*E. anophelis*) infections. Wisconsin and CDC distributed information to public health departments and clinical partners to ensure effective diagnosis, treatment, and surveillance of illnesses. CDC's laboratory continues to receive and analyze *Elizabethkingia* isolates from states across the country to help determine if they are *E. anophelis* species, and if they represent related or different clusters of cases. As of July 20, 2016, CDC has tested several hundred isolates related to the outbreak, including point prevalence surveillance swabs from case patients and contacts, suspected medical and personal care products, and environmental samples. This type of surveillance will continue as a critical component of the epidemiologic, environmental, and laboratory investigation to determine the source of infections.

3. **The Blue Ribbon Study Panel on biodefense emphasized the importance of implementing "One Health" principles in order to address the nation's biodefense needs. But the panel also recognized serious shortcomings, where agencies specialize in either human health or animal health, but where wildlife authorities are "rarely included at all." With the real and escalating risk associated with emerging diseases of wildlife origin, how does the CDC**

**leverage the expertise of the USGS National Wildlife Health Center and academic partners such as University of Wisconsin-Madison to bolster the effectiveness of the "One Health" approach to address emerging infectious disease concerns? What increases in capacity and resources at the National Wildlife Health Center are necessary to support CDC's goals under the "One Health" approach?**

The One Health concept recognizes that the health of humans is connected to the health of animals and the environment. Animals, including wildlife, share our susceptibility to some diseases and environmental hazards. Because of this, animals are not only potential vectors for human disease but can serve as early warning signs of potential human illness. For example, birds often die of West Nile virus before humans get sick with West Nile virus fever.

The USGS National Wildlife Health Center is therefore an essential One Health partner due to its expertise on wildlife issues. CDC is currently discussing a collaboration with the National Wildlife Health Center on a study regarding non-human reservoirs for Zika virus in vertebrate animals such as primates, reptiles, and birds. The National Wildlife Health Center's expertise in wildlife field work would be extremely valuable for the success of the study. The National Wildlife Health Center and the University of Wisconsin-Madison participate in the National Animal Health Laboratory Network (NAHLN), a network of laboratories focused on diseases of animals, such as avian influenza, which have the potential to harm humans. Diagnostic testing through laboratories in the NAHLN can provide vital information to CDC about potential reservoirs of zoonotic diseases throughout the United States. CDC defers to the National Wildlife Health Center to determine the capacity and resource increases that are necessary to monitor disease and assess the impact of disease on wildlife populations.

**Senator Thomas R. Carper:**

1. **In its 2011 Report, the General Accounting Office reported that there is no individual or entity with responsibility, authority, and accountability for overseeing the entire biodefense enterprise and recommended that the Homeland Security Council consider establishing a focal point to oversee these efforts. The number one recommendation included in the Bipartisan Report of the Blue Ribbon Study Panel on Biodefense is to institutionalize biodefense in the Office of the Vice President of the United States to ensure that biodefense will be addressed by every Administration at the highest levels. The second recommendation is to establish a Biodefense Coordination Council at the White House, led by the Vice President.**

    a. **Do you support establishing one individual or entity to coordinate these efforts or think that the existing structure is sufficient?**
    b. **How else could we improve coordination across the government in biodefense activities?**

*Please see HHS responses.*

2. **In its final report, the Blue Ribbon Study Panel issued more than 33 recommendations for action by the Executive Branch. Please explain what activities your Department or Agency is taking to address the select recommendations listed below from the report and note whether the activities have begun, are completed or have not yet started. Please also note recommendations that you do not intend to fulfill and why not. Please provide a response for each recommendation below that applies to your Department or Agency:**

   **c. #8 – Prioritize and align investments in medical countermeasures among all federal stakeholders.**

CDC is part of the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE), which defines and prioritizes requirements for public health emergency medical countermeasures. Created by HHS in 2006, PHEMCE is a coordinated interagency effort led by the ASPR and includes two HHS agencies in addition to CDC: FDA and NIH. PHEMCE also includes interagency partnerships with the DoD, Department of Homeland Security (DHS), Department of Veterans Affairs, and United States Department of Agriculture. PHEMCE coordinates the research, development, procurement, and preparation for the effective utilization of antiviral medical countermeasures among the civilian population.

**e. #10 – Establish a national environmental decontamination and remediation capacity.**

This question applies largely to the Federal Emergency Management Agency (FEMA) and the Environmental Protection Agency (EPA). The response below is relevant to #10(c), regarding studies of those exposed to biologic agents.

The nation depends on emergency responders to preserve the public's safety and health when disasters strike. To successfully meet this challenge, emergency responders must be protected from the hazardous conditions that disasters and other emergencies create, whether natural or manmade. A plan for monitoring emergency responder health and safety is an important part of protecting them.

CDC worked with the U.S. National Response Team (NRT) and a number of federal agencies, state health departments, labor unions and volunteer emergency responder groups to develop the Emergency Responder Health Monitoring and Surveillance (ERHMS) system. The ERHMS framework provides guidelines for protecting the health and safety of emergency responders before, during, and after deployments. This surveillance system was initiated in response to lessons learned from 9-11 and other emergency events, and information and actions recommended under the ERHMS framework can inform decisions regarding the need for long term monitoring of responders. CDC encourages organizations to adopt this system to help ensure the health and safety of responders before, during, and after a response. Additional information about this framework can be accessed at http://www.cdc.gov/niosh/topics/erhms/.

**f. #11 – Implement an integrated national biosurveillance capability.**

The Nation's biosurveillance capability is founded on public health surveillance systems developed and strengthened by state and local health departments with support from CDC. A range of surveillance

systems contribute to the nation's capacity for early detection, rapid characterization, and effective response to public health threats.

CDC is implementing an overarching Surveillance Strategy, including improving standardization and commonality of platforms across CDC systems, reducing duplication, tackling workforce and informatics challenges at CDC and State and local public health systems, and reducing the burden of participation in surveillance for healthcare and public health. Implementation of the Surveillance Strategy will improve the agency's overall capabilities to work with other public and private health systems. The improvements will advance our data systems in a way that clinicians, state and local public health agencies, and CDC can more rapidly share information to take effective public health action to promote health security and reduce reporting burden by eliminating redundant reporting.

Several on-going initiatives support Surveillance Strategy implementation and integration. Each of these initiatives seeks to improve the quality and timeliness of surveillance data reporting to CDC while also reducing burden on, and providing additional value to, STLT health departments. Examples of on-going systems and initiatives included in CDC's overarching surveillance strategy include:

**National Syndromic Surveillance Program:** Promotes and advances a syndromic surveillance system for the timely exchange of data received through the BioSense platform primarily from emergency department visits in participating state and local jurisdictions. These data are used to improve nationwide situational awareness and to enhance responsiveness to hazardous events and disease outbreaks.

**National Notifiable Diseases Surveillance System Modernization Initiative:** This program is a nationwide collaboration enabling local, state, territorial, federal, and international public health agencies to share notifiable disease-related health information received from hospitals, healthcare providers, and laboratories within participating jurisdictions. Public health uses this information to monitor, understand, control, and prevent the occurrence and spread of state-reportable and nationally notifiable infectious and noninfectious diseases, conditions (e.g., measles, viral hemorrhagic fever, anthrax, Legionnaires Disease), and outbreaks. Ongoing improvements will increase reporting standardization, timeliness, and data quality.

**The Electronic Laboratory Reporting Initiative:** This initiative is increasing the proportion of test results reported electronically to health departments and CDC by commercial clinical laboratories and public health laboratories. Building capacity to electronically receive reports of cases of notifiable conditions and track diseases with pandemic potential in real time will enable us to more rapidly share information and take effective public health action.

**The Electronic Death Reporting Initiative:** This initiative has been accelerating and enhancing the completeness of cause-of-death reporting nationwide, enabling near real-time mortality surveillance. The initiative currently funds 35 states to increase timeliness of transmission of mortality records to CDC. CDC plans to provide additional funding to states to work on timeliness and quality of the mortality records, with an emphasis on mortality records for drug-related causes of deaths. Since 2010 timely transmittal (within 10 days of death) of mortality records from states to CDC increased from 7% to 47%. Faster transmission enables CDC to transform the National Mortality System into a near, real-time public health surveillance system.

**Workforce development:** The CDC Surveillance Strategy includes development of a public health workforce training and support plan to improve surveillance systems and to address technological considerations practitioners face. Training and development will ensure a healthy informatics vision and governance, skilled workforce, and effective use of a well-designed system.

**CDC Integrated Surveillance Platform:** CDC is modernizing its systems by designing, developing, and adopting an initial set of services that will form the beginnings of a cloud and web based data collection information technology platform. When fully implemented, this platform would support public health surveillance data collection, analysis, and dissemination efforts across the agency and with public health partners. The Platform would enable public health programs to use surveillance data more quickly and efficiently.

**i. #14 – Improve surveillance of and planning for animal and zoonotic outbreaks.**

Although human and animal health agencies typically are in independent government departments, these agencies work collaboratively on public health issues involving the animal-human-ecosystem interface using an interdisciplinary One Health approach. Establishing and maintaining relationships between these agencies prior to outbreaks is essential to an effective response. To that end, animal health and human health programs within CDC, FDA, the United Stated Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS), USDA Food Safety and Inspection Service (FSIS), and DHS maintain liaisons embedded in each other's organizations to ensure ongoing and daily collaboration in surveillance, detection, and response. In addition, CDC, FDA and USDA have more formal institutional collaboration in certain areas. For example, the three agencies, together with state and local health departments, run the National Antimicrobial Resistance Monitoring System for Enteric Bacteria (NARMS), which tracks antibiotic resistance across food animals and human foodborne diseases.

Recent public health emergencies that involved One Health collaboration between CDC and USDA include a variety of foodborne outbreaks, human salmonellosis linked to backyard poultry flocks and other animals, and One Health response to Highly Pathogenic Avian Influenza H5 Outbreaks. Additionally, FDA and USDA worked very closely to investigate the initial outbreak of Porcine Endemic Diarrhea Virus in the U.S. These collaborative investigation teams allow for real-time sharing of human and animal health data to better identify the source of the outbreaks and reduce the risk of continued transmission and illness to both people and animals.

**j. #15 – Provide emergency responders with the resources they need to keep themselves and their families safe.**

CDC provides emergency responders with resources to keep themselves and their families safe through several programs.

- Anthrax vaccine
  - Anthrax vaccine from the Strategic National Stockpile (SNS) supports the DoD's vaccination program for active duty service members, as part of the joint stockpiling arrangement between DoD and CDC established in 2008. Through this interagency agreement, anthrax vaccine from SNS holdings is held in a reserved quantity for DoD

requirements and delivered prior to expiration in order to meet the demand for anthrax vaccination of DoD personnel. DoD reimburses CDC for the vaccine received to fund replacement of the product delivered to DoD.
    - CDC and HHS support the DHS' development of an anthrax vaccination program pilot for first responders. CDC commits to providing vaccine from the SNS that is near its expiration date to support the pilot program and supports meeting the goals of implementing a safe and effective vaccination program without compromising other ongoing preparedness activities or reducing response capabilities through participation in the pilot.
- Disaster Science Responder Research (DSRR) Program
    - The goals of the DSRR are: 1) to identify critical topic areas needing further research to better protect emergency responders, and 2) to implement a framework that allows for responder research to be started quickly when a disaster or emergency occurs, without interfering with the response itself. The types of research conducted may include: the impact of a novel exposure, unexpected or severe health effects, the effectiveness of a proposed intervention, mental health/resilience issues, disease outcomes with latency periods, and take-home exposures. We believe the results of this research will lead to reduced health risks for responders, and to improvements in the effectiveness of emergency responses. Additional information can be found on our website: http://www.cdc.gov/niosh/topics/disasterscience/default.html
- National Personal Protective Technology Laboratory (NPPTL)
    - Established in 2001 with a primary focus on improving worker safety and health through better personal protective technologies.
    - Mission is to prevent work-related injury, illness and death by advancing the state of knowledge and application of personal protective equipment (PPE).
    - One of the key goals of the NPPTL is to develop the scientific basis for PPE guidelines and requirements in advance of a biological event. Through audits and respirator certification, CDC improves the quality and inventory of respiratory protection for workers in multiple industries, including those involved in biological response. In FY 2015, CDC completed 364 certified respirator decisions, including 733 new approvals, and 173 complete respirator audits. CDC supported the use of PPE in the Ebola response by completing testing on PPE ensembles used in West Africa to provide additional heat stress mitigation guidance and improving the test methods used for assessing liquid and viral barrier performance of PPE.
    - CDC also collaborated with the Occupational Safety and Health Administration (OSHA) to publish recommendations for hospital respiratory protection program managers.
- Fire Protection Research Foundation
    - Initiated in FY 2015, CDC is collaborating with the Fire Protection Research Foundation to establish cleaning procedures for firefighter PPE.
    - This research and development effort is being conducted to establish clear and definitive guidance for the fire services for applying cleaning and decontamination procedures that effectively remove both chemical and biological contaminants. Firefighter exposure to persistent harmful contaminants in PPE is an increasingly

serious problem both on the fire ground to highly toxic substances including a variety of carcinogens, and more insidiously to an increasing range of infectious pathogens that are encountered in patient care and different emergency operations.

- Study to evaluate DHS' chemical, biological, radiological, and nuclear (CBRN) assessments
    - Approved in FY 2016, CDC is evaluating the latest DHS hazard assessments to identify the most likely chemical and radiological agent threats that would be used in an intentional or unintentional large scale release or a natural disaster.
    - Assessment will include testing the filtration efficacy of currently fielded National Institute for Occupational Safety and Health (NIOSH) CBRN certified air purifying respiratory protective devices (APRs) against these chemical and radiological agents. It is vital to know whether the currently fielded NIOSH CBRN APRs can provide adequate respiratory protection against these newly emerged chemical and radiological agent threats to ensure the first responders are protected.

**l. #18 – Establish and utilize a standard process to develop and issue clinical infection control guidance for biological events.**

CDC is the lead federal agency for developing infection control guidelines that U.S. health care facilities can use when implementing local protocols and procedures. Key related activities include:

- Healthcare Infection Control Practices Advisory Committee (HICPAC):
    - CDC maintains this federal advisory committee that includes experts from throughout the federal government and private sector, and representatives from professional societies, hospital associations, public health associations, healthcare accreditation organizations, and consumer groups.
    - HICPAC advises the agency on healthcare-related issues and infection control.
    - Advisory committee meetings and calls are open to the public; all draft recommendations of the advisory committee are posted in the Federal Register for public comments, which are summarized and discussed at public meetings. Once finalized, recommendations such as these sometimes are promulgated into regulations and oversight requirements by occupational safety and health regulatory authorities such as OSHA and the Centers for Medicare & Medicaid Services (CMS), as well as other non-governmental entities like The Joint Commission.
- Multidisciplinary group of CDC experts:
    - Convened during infectious disease public health emergencies, this group includes CDC experts in healthcare infection control and quality, occupational safety and health, clinical experts, and experts in particular pathogens (influenza virus, Ebola virus, Middle East Respiratory Syndrome Coronavirus) to review existing healthcare recommendations.
    - In situations where a new or emerging infection occurs and there is a lack of available data, CDC develops interim guidance based on the best information available (e.g., existing CDC guidance for similar diseases, current epidemiologic and laboratory

information, peer-reviewed evidence, and expert opinion), including published literature and field experience. Interim guidance is specifically written to allow flexibility in implementation so that protocols and procedures can take facility-specific characteristics (like facility design or types of supplies available) into consideration across health care settings.

- Draft guidance is shared with other federal health agencies as part of the formal governmental clearance, and input is incorporated before posting as interim guidance on CDC's website. During the process, CDC also gets input from clinical experts (e.g., Emory University and Nebraska Medical Center during the outbreak involving the Ebola virus).
- CDC actively engages the healthcare, occupational safety, labor union and public health communities to disseminate the recommendations. Feedback from users about the interim guidance, along with emerging information, is used to refine recommendations in real-time throughout the emergency, with updates documented on the CDC website.

**m. #22 – Develop and implement a Medical Countermeasure Response Framework.**

CDC currently develops, distributes and updates guidance on medical countermeasure (MCM) planning requirements for state and local partners. In 2013, CDC released "Distributing and Dispensing Strategic National Stockpile Assets: A Guide for Preparedness, Version 11."[1]

This guidance includes information and planning considerations on all aspects of the state and local functions necessary to request, receive, and utilize MCMs from SNS. It provides detailed information on the resources and capabilities required for all hazards preparedness, and recommends additional development of threat specific plans to address the challenges associated with differing threats to public health. For example, effective response to a large scale anthrax exposure requires different MCM dispensing mechanisms and timelines than those required during an influenza pandemic. CDC is working to develop additional threat specific operational and clinical guidance and information to support the development and improvement of these threat specific plans and capabilities at the state and local level. In addition, some medical countermeasures held in the SNS require specific guidance for clinical use in response to public health emergencies. CDC develops this guidance, based on current science and research data, and publishes it for use by planners and clinicians preparing to use medical countermeasures from the SNS.

The majority of SNS-held products are for use in an emergency in accordance with their FDA approved label instructions. Certain SNS-held products do not have FDA-approved indications for their intended use in a public health emergency, and for these products, CDC must use regulatory mechanisms such as Emergency Use Authorizations or Investigational New Drug protocols to provide appropriate frameworks for safe and effective use of these products in an emergency. CDC develops these

[1] This document is available to state and local planners through password protected resource and technical assistance websites maintained by CDC.

mechanisms for each individual product, as required, in collaboration with FDA, based on current science and available research and other evidence. For certain MCM that are FDA-approved and being used for their intended indication but may have some deviations from the approved labeling, Emergency Use Instructions may be generated by CDC.

As they become available, clinical guidance documents are posted on the CDC website, and regulatory documents such as Emergency Use Instructions for SNS-held products are on the password protected CDC JOIN External Partners SharePoint site, to allow access by our state and local partners evaluating and expanding on their existing MCM response plans. As required information becomes available CDC is prioritizing and developing additional guidance as needed for SNS-held products requiring additional guidance for clinical use.

n. **#23 – Allow for forward deployment of Strategic National Stockpile assets.**

CDC holds SNS products in centralized storage facilities across the country for rapid deployment through a tested network of transportation partners. Each state has plans to receive from CDC and distribute SNS medical countermeasures to local communities as quickly as possible. Product procured for the SNS is held in centralized storage under a rigorous quality control program utilizing security, environmental monitoring and routine inventory inspections to ensure that each countermeasure is in optimal condition and ready for rapid deployment. This level of quality control allows CDC to participate in the joint Food and Drug Administration and Department of Defense Shelf Life Extension Program to extend the useful life of SNS products.

CDC reviews and evaluates requests from jurisdictions that request forward deployment of medical countermeasure resources from the SNS. Since the safety and stability of the product is one of the most critical factors to consider, removing product from SNS inventory for forward deployment into state and local custody requires extensive work by both parties. Jurisdictions requesting forward deployment must address and meet required standards for security, environmental control and accountability to ensure the availability and efficacy of the product in an emergency, including specific temperature control requirements for specific products. CDC must also evaluate whether the request for forward deployment of product to a jurisdiction reduces CDC's capability to use that product to respond to an event in another location.

**o. #24 – Harden pathogen and advanced biotechnology information from cyber-attacks.**

CDC promotes secure use of information and information technology and protects sensitive data by:

- Managing firewalls that protect CDC's network and systems.
- Scanning CDC's network and systems for vulnerabilities that can cause damage.
- Responding to incidents that have a negative impact on CDC's network and systems.
- Establishing policies and guidelines that promote a secure operating environment for CDC.
- Providing training that promotes security awareness for CDC staff.
- Approving software for safe use in the CDC work environment.

In addition, regulations issues by HHS and USDA under the Federal Select Agent Program (FSAP) (42 CFR 73.11; 9 CFR 121.11; 7 CFR § 331.11), require the following security for IT systems to ensure that only those approved for access to biological select agents and toxins can gain access through the IT systems:

- Ensure that all external connections to systems which manage security for the select agent and toxin registered space are isolated or have controls that permit only authorized and authenticated users;
- Ensure that authorized and authenticated users are granted access to select agent and toxin related information, files, equipment (e.g., servers or mass storage devices) and applications as necessary to fulfill their roles and responsibilities, and that access is modified when the user's roles and responsibilities change or when their access to select agents and toxins is suspended or revoked;
- Ensure that controls are in place that are designed to prevent malicious code (such as computer virus, worms, spyware) from compromising the confidentiality, integrity, or availability of information systems which manage access to select agent and toxin registered spaces;
- Establish a robust configuration management practice for information systems to include regular patching and updates made to operating systems and individual applications; and
- Establish procedures that provide backup security measures in the event that access control systems, surveillance devices, and/or systems that manage the select agent and toxin records maintenance requirements are rendered inoperable.

**r. #28 – Fully prioritize, fund, and incentivize the medical countermeasure enterprise.**

CDC is part of the Public Health Emergency Medical Countermeasures Enterprise (PHEMCE), which defines and prioritizes requirements for public health emergency medical countermeasures. PHEMCE, created by the Department of Health and Human Services (HHS) in 2006, is a coordinated interagency effort led by the HHS Office of the Assistant Secretary for Preparedness and Response (ASPR) and includes two HHS agencies in addition to CDC: FDA and the National Institutes of Health. PHEMCE also includes interagency partnerships with the Department of Defense, Department of Homeland Security, Department of Veterans Affairs, and the United States Department of Agriculture. PHEMCE coordinates the research, development, procurement, and preparation for the effective utilization of antiviral medical countermeasures among the civilian population. CDC collaborates with PHEMCE to prioritize and adjust the SNS formulary annually based on current threats and available funding.

PHEMCE standardizes the civilian medical countermeasure requirement development process to address the national ability to utilize medical countermeasures in a public health emergency effectively. The PHEMCE medical countermeasure requirement process leverages:

- Public health consequence modeling
- Subject matter expert evaluations
- Estimates of current national response capabilities

The medical countermeasure requirement process and subsequent stockpiling and procurement goals stem from sound scientific, medical, and epidemiological principles and result in a national stockpile of medical countermeasures CDC will deliver to state and local public health officials for use during a public health emergency. PHEMCE teams represented by intergovernmental agency experts conduct formulary reviews to develop or revise recommendations as to which specific medical countermeasures will fulfill stockpiling goals. PHEMCE and CDC use current clinical practice, market availability, and the best application of public funds to guide acquisition targets and decisions. CDC also uses PHEMCE recommendations to prepare the SNS Annual Review Report that informs HHS budget formulation for medical countermeasures held in the SNS.

**v. #32 – Review and overhaul the Select Agent Program.**

The Federal Select Agent Program (the collaboration between CDC's Division of Select Agents and Toxins and APHIS' Agriculture Select Agent Services) underwent three reviews that were publicly released in October of 2015: (1) the CDC 90 Day Internal Review of the Division of Select Agents and Toxins, ordered by the CDC Director, (2) the National Security Council sponsored the Federal Experts Security Advisory Panel review, and (3) the White House sponsored Fast Track Action Committee review. The three review reports, each of which have been released to the public, include recommendations designed to strengthen the federal government's biosafety and security practices and oversight, through actions by the FSAP and more broadly by governmental and private entities. The FSAP is in the process of addressing the recommendations contained in these reports. An update on its progress towards implementation of these recommendations can be found at: http://www.cdc.gov/phpr/dsat/review_initiatives.htm. We believe CDC should continue to implement the recommendations from the three recent reviews, and further reviews should be deferred until after the current processes have run their courses.

**3. The Blue Ribbon Study Panel, GAO and other experts have recommended the development of a national biodefense strategy. To date, federal agencies have produced several strategic documents that address different aspects of biodefense, including the National Health Security Strategy and the National Biosurveillance Strategy. Do you believe that existing strategy and policy documents provide sufficient coordination of biodefense activities across the federal government? What elements should be included in a unified national strategy for biodefense?**

*Please see HHS response.*

**4. The Blue Ribbon Study Panel recommended the development of a unified budget for biodefense spending, and estimated that roughly $6 billion is spent every year on biodefense and related hazards. Please detail how much your Department or Agency spent on biodefense efforts (categorized by Threat Awareness, Prevention and Protection, Surveillance and Detection, and Response and Recovery activities, as defined by Homeland Security Presidential Directive 10) from Fiscal Years 2007-2016.**

CDC's Public Health Preparedness and Response activity works 24/7 to protect the safety, security, and health of the United States from public health threats, foreign and domestic, intentional and naturally

occurring. CDC provides life-saving responses to chemical, biological, radiological, and nuclear threats, as well as other disasters, outbreaks, and epidemics. These activities are essential to CDC's goal to protect Americans' health and safety by:

- Supporting state and local health department preparedness activities
- Responding to public health emergencies
- Ensuring an available supply of medical countermeasures
- Overseeing and regulating laboratories that import and possess the most deadly pathogens and toxins
- Providing comprehensive situational awareness
- Working 24/7 to respond to calls from medical professionals and the general public
- Building international Emergency Operation Center capacity and enhancing global health security

The table below, based on CDC budget lines, shows historical funding levels for certain public health preparedness and response activities, as well as funding for biosurveillance, anthrax vaccine research, continuity of operations, and cyber security. Although the table captures funding for certain programs that contribute to biodefense, and funding for those programs make up a significant portion of CDC spending on biodefense, there is other work throughout the Agency that contributes to biodefense and which is not reflected in the table, such as the Electronic Laboratory Reporting Initiative and the Electronic Death Reporting Initiative.

**Centers for Disease Control and Prevention**
**Preparedness and Response Activity Budget**
**(budget resources in millions of dollars)**

| | FY 07 | FY 08 | FY 09 | FY 10 | FY 11 | FY 12 | FY 13 | FY 14 | FY 15 | | FY 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Enacted | Emrgncy | Enacted |
| CDC Preparedness and Response Capability* | 157.54 | 147.52 | 163.36 | 131.29 | 126.35 | 117.54 | 111.42 | 133.8 | 133.8 | --- | 138.8 |
| BioSense | 52.01 | 34.39 | 34.39 | 34.4 | 33.77 | 20.73 | 19.65 | 23.37 | 23.35 | | 23.0 |
| State and Local Preparedness** | 766.66 | 746.04 | 746.60 | 760.99 | 664.29 | | 623.21 | 661.04 | 661.05 | --- | 668.2 |
| Strategic National Stockpile*** | 496.35 | 551.51 | 570.31 | 595.66 | 591.00 | 533.79 | 477.58 | 549.34 | 534.35 | --- | 575.00 |
| Domestic Ebola Response | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 576.00 | N/A |
| Total | 1,472.56 | 1,479.46 | 1,514.66 | 1,522.34 | 1,415.41 | 1,329.48 | 1,231.86 | 1,367.55 | 1,352.55 | 576.00 | 1,405.00 |

*Includes Upgrading CDC Capacity, Botulinum Toxin Research, Quarantine, Real-Time Lab Reporting, and Anthrax Vaccine Research
** Includes Academic Centers and All Other State and Local Capacity Funding lines
***Funding in FY 2007 and FY 2008 for Strategic National Stockpile program include a comparability adjustment of -$7.4 million. In FY 2009 budget, CDC transferred the funds to support Business Services Support activities.

5. **Upon the release of the National Biosurveillance Strategy in July 2012, a strategic implementation plan for the strategy was slated for completion within 120 days. What is the status of the implementation plan?**

*Please see HHS response.*

**Please describe how the Centers for Disease Control and Prevention coordinates biosurveillance programs and policy with other federal agencies, per the National Biosurveillance Strategy. If the implementation plan has been completed, please provide it to this Committee.**

CDC coordinates across the agency and federal government in various ways, including sharing of information directly or through the National Biosurveillance Integration Center, collaborating on policy development coordinated through the Executive Branch (e.g., the Office of Science and Technology Policy's Biodefense Science and Technology Capability Review), collaborating on joint projects (e.g., Global Health Security Agenda implementation with DoD, State Department, and others), and working directly at the program level to optimize resources, especially with regard to capacity building at the domestic and foreign levels.

A precursor to the 2012 National Biosurveillance Strategy was CDC's National Biosurveillance Strategy for Human Health and accompanying Concept Plan for implementation. This document was used as an initial guide for CDC's internal and external biosurveillance coordination. After the release of the National Biosurveillance Strategy in 2012, CDC participated in the National Security Council-led interagency effort to draft the accompanying implementation plan.

**Senator Ron Johnson:**

1. **What metrics has the CDC or its partners at HHS collected regarding the success of its public outreach in West Africa related to Ebola?**

CDC worked with the governments and other response partners in countries that were heavily affected by Ebola in West Africa to design and deliver evidence-based strategies for health promotion on Ebola prevention and control, and medical care. Examples of CDC-led activities include:

- Development of comprehensive messaging guides
- Design of low literacy communication materials
- Interactive radio programs such as "Ebola Big Idea of the Week"
- Training of journalists and health personnel on Ebola risk communication
- Hot spot site visits and joint outreach with surveillance teams
- Community-based ambulance exhibitions (to reduce fear of using ambulances)
- Technical guidance to local social mobilization partners including non-governmental organization (NGO) consortiums

CDC conducted or supported multiple national household surveys to assess changes in the public's knowledge, attitude, and practices (KAP) relating to Ebola prevention and medical care in the affected countries in West Africa. In addition, CDC conducted rapid qualitative assessments to generate a more in-depth understanding of cultural factors linked to Ebola transmission, and used the findings to tailor intervention strategies and advise the respective governments.

In Sierra Leone, CDC supported four national household KAP surveys with information collected from more than 10,000 cumulative respondents between August 2014 and July 2015. The results showed major improvements in the public's knowledge, attitudes, and practices related to Ebola:

- Knowledge that Ebola virus can be prevented by avoiding contact with bodily fluids increased from 87% to 94% between August 2014 and December 2014
- Knowledge that Ebola virus can be prevented by avoiding traditional burials that involve washing or touching of the corpse increased from 85% to 93% between August 2014 and July 2015
- Belief that spiritual healers can successfully treat Ebola virus decreased from 19% to 5% between August 2014 and July 2015
- Acceptance of safe burials increased from 65% to 79% between October 2014 and July 2015
- Intention to call the health facility when Ebola virus is suspected increased from 71% to 91% between August 2014 and July 2015
- Frequent handwashing increased from 66% to 87% between August 2014 and July 2015

Similarly, the Liberia KAP survey supported by CDC epidemiologists in December 2014 revealed high awareness and knowledge such that over 9 in 10 respondents knew that Ebola virus can be transmitted by washing or touching an infected corpse. The KAP survey supported by CDC in Guinea also found high knowledge of Ebola virus prevention (ranging from 73% to 83%) especially in the geographic areas where communication efforts were intensified. Additional analysis from Sierra Leone demonstrated that when people received Ebola information from multiple reinforcing sources they were more likely to have correct Ebola knowledge and able to adopt behaviors that prevent infection. CDC is now building upon these lessons learned from Ebola health promotion to strengthen the capacity of governments and partners in the affected West African countries to execute effective risk communication strategies to prevent Ebola virus and other emerging global health threats elsewhere.

**2. What are the interim results regarding potential vaccines that will be effective against Ebola?**

Currently, there is no FDA-approved vaccine available for Ebola virus. Experimental vaccines for Ebola virus are under development but they have not yet been fully tested for safety or effectiveness. Phase I and II/III trials are being conducted including in the U.S. and in several European and African countries. CDC, in partnership with the government of Sierra Leone, launched the Sierra Leone Trial to Introduce a Vaccine against Ebola (STRIVE) in April 2015. This trial is still underway. More than 8,000 individuals were vaccinated with the rVSV-ZEBOV vaccine through STRIVE, just one of three large rVSV-ZEBOV vaccine studies being conducted in West African Ebola-affected countries. WHO and NIH are leading the other two studies.

Because of effective control of the Ebola epidemic, cases declined dramatically during the trial. As a result, STRIVE will not be able to measure vaccine efficacy. However, STRIVE does have a sub-study in which blood samples from vaccinated participants are being tested to determine if participants' immune systems responded to the vaccine by making antibodies to protect against Ebola virus and how long these antibodies may last.

**Senator Rob Portman:**

**As you know, in 2013 the President signed a reauthorization of the Pandemic and All-Hazards Preparedness Act. This reauthorization included funding for public health and medical preparedness program, such as the Hospital Preparedness Program. In FY 2014 over $255 million went out in grants to state and local health departments to assist the nation's healthcare system in preparing for public health emergencies.**

**Yet, it seems when hospitals were put to the test during the Ebola response, there were significant gaps in the ability of the hospital to adequately treat the patient and protect health care workers.**

**It is clear that we must do more to ensure every hospital is ready if a patient with Ebola or other highly infectious disease walks into their emergency room. More so, we must ensure that there are hospitals in regions throughout the country that are specifically designated to treat these type of patients.**

**a. What was lacking from the Hospital Preparedness Program and other programs in PAHPA that led to hospitals not being adequately prepared for Ebola?**

Investments made through Hospital Preparedness Program (HPP) funding support preparedness efforts across the nation's health care system to better address new and emerging threats to public health when day-to-day capacities of health and emergency response systems are exceeded.

For much of its history, HPP funding has supported the purchase of critical resources needed to respond to disasters. Some resources are specific medical resources; others include communication systems, registry, patient tracking, information sharing, and credentialing systems that require sustainment. Without this funding, many states would be unable to properly respond and save lives without other federal support. Because of HPP investments, in recent years, many demonstrations of communities were able to respond with little to no federal support at the time of an event.

Regarding preparedness for Ebola, the Department of Health and Human Services (HHS), and HPP specifically, worked to enhance preparedness across the nation's health care infrastructure using existing tools and resources as well as newly appropriated funding. Utilizing emergency supplemental funding, HHS developed a regional approach to caring for future Ebola patients. Building upon the state and jurisdiction-based tiered hospital approach and meeting Congress' regional directive, HPP provided awardees with $194.5 million of Ebola supplemental funding to establish a nationwide, regional treatment network for Ebola and other infectious diseases.[2] This approach balanced geographic need, differences in institutional capabilities, and accounted for the potential risk of needing to care for an Ebola patient. While preparedness for Ebola was the focus, it is likely that preparedness for other novel,

[2]CDC, *Interim Guidance for U.S. Hospital Preparedness for Patients under Investigation (PUIs) or with Confirmed Ebola Virus Disease (EVD): A Framework for a Tiered Approach*, http://www.cdc.gov/vhf/ebola/healthcare-us/preparing/hospitals.html.

highly pathogenic diseases will also be enhanced. Furthermore, to prepare for and provide safe and successful care of patients with Ebola, HHS awarded an additional $12 million to establish a National Ebola Training and Education Center (NETEC). The NETEC will offer state health departments, regional Ebola and other special pathogen treatment centers, state and jurisdiction-based Ebola treatment centers, and assessment hospitals expertise, training, technical assistance peer review, monitoring, and recognition.

It is important to note that the supplemental funding for Ebola built upon more than a decade of HPP investments that bolstered health care system preparedness and response at hospitals and other health care providers across the nation. Beginning on April 15, 2014, and prior to the award of supplemental funding, HPP began issuing health care system guidance, checklists, and training documents, offered the flexibility and processes to use cooperative agreement funds to directly address Ebola, and convened national calls and webinars to provide updated information about Ebola to physicians, nurses, hospital executives, emergency medical service providers, and public health leaders, reaching hundreds of thousands of the nation's frontline health workforce.

**b. How can we ensure that hospitals are prepared for future highly infectious diseases like Ebola or Zika in the future?**

A few important lessons learned from the national health care system's response to Ebola include the need for sustained health care worker safety, from clinicians and laboratory workers to ancillary staff; recognizing that care of Ebola patients is clinically complex and demanding; and understanding that early case recognition is critical for preventing spread and improving outcomes. These lessons highlight the importance of sufficient and stable preparedness funding and the need for a national network of hospitals for treating highly pathogenic infectious diseases, such as Ebola.

HHS has taken several steps to ensure a strong and resilient national health care system. The funding provided through the HPP Ebola funding opportunity (financed from Ebola supplemental appropriations) is intended to ensure the nation's health care system is ready to safely and successfully identify, isolate, assess, transport, and treat patients with Ebola or persons under investigation for Ebola, and that it is well prepared for a future Ebola or Ebola-like outbreak. While the focus in the Ebola supplemental appropriation is on preparedness for Ebola, it is likely that preparedness for some other novel, highly pathogenic diseases will also be enhanced through these activities. Through the Ebola funding administered by HPP, the U.S. now has a network of 91 (as of August, 2016) Ebola treatment centers and 196 (as of August, 2016) assessment hospitals for their states or jurisdictions. The funding also supports health care coalitions (HCCs) to prepare frontline hospitals, emergency medical services, and the overall health care system. In addition, HPP funding established ten (as of June, 2016) regional Ebola and other special pathogen treatment centers, which can be ready within a few hours to receive a confirmed Ebola patient from their region, across the U.S., or medically evacuated from outside of the U.S. (as necessary). These hospitals will also have enhanced capacity to care for highly infectious diseases.

Moreover, HPP has worked to foster infectious disease training and education throughout the country through a separate funding opportunity jointly established with the Centers for Disease Control and Prevention (CDC). The NETEC is comprised of staff from hospitals that have successfully evaluated

and treated Ebola patients in the U.S. In collaboration with staff from CDC and ASPR, the NETEC offers expertise, education, training, technical assistance, peer review assessments, and recognition reporting to regional Ebola and other special pathogen treatment centers, state and jurisdiction-based Ebola treatment centers, and assessment hospitals.

CDC is conducting innovative research to identify new and improved ways to prevent the spread of infectious diseases like Ebola in healthcare facilities through investments in the Prevention Epicenters Program. The Prevention Epicenter program is a unique research platform through which CDC collaborates with academic investigators across 11 sites to conduct innovative infection control and prevention research, developing and testing innovative approaches to preventing infections and improving patient safety in healthcare settings. In 2015, CDC awarded a total of $11 million to six of these Prevention Epicenters to expand infectious disease research efforts. The goal is to help doctors and nurses better protect the health and safety of their patients, and each other, from high-risk disease threats through projects focused on:

- Preventing the spread of infectious agents in healthcare facilities, including Ebola virus
- Evaluating best approaches to using personal protective equipment
- Minimizing the role of the healthcare environment in infection transmission

HPP is also targeting preparedness for infectious diseases through its annual cooperative agreement program. In the continuation guidance for budget period five (July 2016 to June 2017), HPP awardees must:

- work to establish new partnerships with infection control or prevention programs in their jurisdictions that can advance the development of stronger health care system infection control and prevention programs;
- enhance partnerships to ensure cross-discipline information sharing among state, local, and territorial public health preparedness programs and HCC members, surveillance programs, communicable disease programs, and health care associated infection control programs; and
- evaluate state, HCC, and hospital needs for personal protective equipment and training resulting from lessons learned during the 2014 Ebola response.

Further, HPP awardees in jurisdictions located on the U.S.-Mexico border or the U.S.-Canada border must conduct activities that enhance border health, particularly regarding disease detection, identification, investigation, and preparedness and response activities related to emerging diseases and infectious disease outbreaks (whether naturally occurring or due to bioterrorism). This focus on cross-border preparedness reinforces the U.S. public health and health system preparedness whole of community approach, which is essential for local to global threat risk management and response to actual events regardless of source or origin.

**Senator Clair McCaskill:**

**1. I asked Dr. Lurie about how Anthrax ended up in the strategic national stockpile because my staff received documents showing that this was not originally a priority for the strategic national**

**stockpile, and in response, she stated that "It is a therapeutic that potentially could be effective against an antibiotic resistant anthrax infection and when present antibiotic therapy is not working." This answer sounds very theoretical to me. It "*potentially could*" be effective in the very specific situation where we have an antibiotic resistant anthrax infection AND when present antibiotic therapy isn't working.**

**Do we know how or if Anthrax works, and, if not, what is the reasoning behind using our limited funding on it for the strategic national stockpile when several other priorities have yet to be funded?**

CDC collaborates with PHEMCE to prioritize and adjust the SNS formulary annually based on current threats and available funding. PHEMCE and CDC use current clinical practice, market availability, and the best application of public funds to guide acquisition targets and decisions.

Abthrax (raxibacumab) is FDA approved for both treatment and post-exposure prophylaxis of inhalational anthrax when administered in combination with recommended antibacterial drugs. Raxibacumab increased survival in animal studies when administered by itself (44% of rabbits survived compared with no survivors in the control group, and 64% of nonhuman primates survived compared with no survivors in the control group) and in combination with antimicrobial drugs (82% of rabbits survived compared with 65% given levofloxacin alone). CDC guidance recommends that an antitoxin should be added to combination antimicrobial drug treatment for any patient for whom there is a high level of clinical suspicion for systemic anthrax.[3]

BARDA purchased Abthrax currently in the stockpile. CDC will not purchase Abthrax for the SNS with appropriated funding until FY 2019, as outlined in the PHEMCE Multi Year Budget.

AVA (BioThrax) is FDA approved for pre-exposure prophylaxis of anthrax and post-exposure when administered in conjunction with recommended antibacterial drugs. The FDA approved indication for Post-exposure prophylaxis was based on the Animal Rule. The FDA approved indication for post-exposure prophylaxis (PEP) was granted under the Animal Rule Summary. The ability of BioThrax to increase the probability of survival after stopping post-exposure antibiotic treatment was assessed in rabbits. Rabbits treated with both antibiotics and BioThrax had a survival rate of 70% to 100%, depending on the vaccine dose administered. In contrast, in two studies of rabbits that received only antibiotic treatment, survival rates were 44% and 23% respectively. The U.S. Advisory Committee on Immunization Practices recommends 60 days of antimicrobial drug prophylaxis for immediate protection and a 3-dose series of BioThrax for long-term protection after exposure to anthrax. To ensure adequate and continued protection, everyone exposed to aerosolized *Bacillus anthracis* spores should

[3] Hendricks KA, Wright ME, Shadomy SV, Bradley JS, Morrow MG, Pavia AT, et al. Centers for Disease Control and Prevention expert panel meetings on prevention and treatment of anthrax in adults. Emerg Infect Dis. 2014 Feb. http://wwwnc.cdc.gov/eid/article/20/2/13-0687_intro

receive a full 60 days of PEP antimicrobial drugs, whether they are unvaccinated, partially vaccinated, or fully vaccinated.[4, 5]

**2. When did the acquisition process begin for glanders, and where are you in that process?**

PHEMCE-approved procurements for antimicrobials for *Burkholderia mallei* (glanders) and *Burkholderia pseudomallei* (meliodosis) for post-exposure prophylaxis and treatment are slated to begin in FY 2016 and FY 2017. The procurements will be spread out over a number of years according to lifecycle management principles, so that all of the MCM will not expire at the same time.

**3. Dr. Lurie's QFR response also noted that generic antibiotics have been purchased for the Strategic National Stockpile to fulfill requirements for countermeasures against exposure to tularemia and plague. But those purchases weren't included in the information my staff received either. Did HHS negotiate lower prices for these generic antibiotics since they were bought in such high quantities?**

With the exception of gentamicin, antimicrobials used for plague and tularemia post-exposure prophylaxis and treatment are also used for anthrax; since the quantities required for anthrax generally exceed those needed for plague or tularemia, they are purchased under the anthrax umbrella of antimicrobials. Generic forms of these antimicrobials have been available and stockpiled for years. For many products, CDC is able to purchase required quantities for the SNS through negotiated contracts at the best price for the government, but other products, especially those that are widely available and generally low cost are subject to rapid price increases if there is a market shortage and require reconsideration. As with all procurements, CDC manages price fluctuations through collaboration with PHEMCE partners and manufacturers when price changes exceed predictable norms. In addressing challenges of this nature, CDC follows the prescribed protocol of adhering to PHEMCE's recommendations regarding prioritization of requirements and works with the manufacturers to adapt current procurement and future projections based on product availability and purchase price.

[4] Wright JG, Quinn CP, Shadomy S, Messonnier N. Use of anthrax vaccine in the United States: recommendations of the Advisory Committee on Immunization Practices (ACIP), 2009. MMWR Recomm Rep. 2010;59 (RR-6):1–30. PubMed.

[5] http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm474027.htm

**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2016-12-01T14:09:43-05:00
**Importance:** Normal
**Subject:** November 4th Grade Pass Redemption Report
**Received:** 2016-12-01T14:10:12-05:00
EKIP Redemption Data 9-1-2016 - 11-30-2016.xlsx

Hello all,
Attached is the latest 4th Grade Pass Redemption Report. Pass issuance continues to be strong with an overall increase of 153% over last year at this time.  Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

# Every Kid in a Park 4th Grade Pass

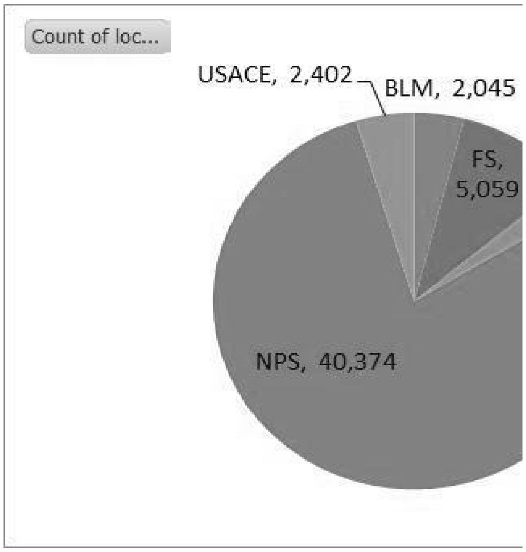
**Reported in Redemption Site 9/1/2016 - 11/30/2016**

**FOR INTERNAL USE ONLY**

## Grand Total **51,167**

| | |
|---|---|
| **BLM** | **2,045** |
| California BLM Office | 716 |
| Eagle Lake BLM Field Office | 351 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| National Historic Trails Interpretive Center | 171 |
| Red Rock Canyon National Conservation Area BLM | 167 |
| Nevada BLM Office | 83 |
| Redding BLM Field Office | 83 |
| Red Rock Canyon National Conservation Area - BLM | 79 |
| Ukiah BLM Field Office | 71 |
| Rio Puerco BLM Field Office | 58 |
| Colorado BLM Office | 17 |
| Utah BLM Office | 4 |
| Royal Gorge BLM Field Office | 3 |
| Miles City BLM Office | 2 |
| Grand Junction BLM Field Office | 2 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 1 |
| Rock Springs Field Office - BLM | 1 |
| Eugene District BLM Office | 1 |
| Palm Springs - South Coast BLM Field Office | 1 |
| **FS** | **5,059** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Stanislaus NF - Mi-Wok District | 500 |
| Lincoln NF - Sacramento District | 397 |
| US Forest Service Region 9 | 331 |
| Cibola NF - Main Office | 292 |
| Caribou-Targhee NF - Ashton/Island Park District | 280 |
| US Forest Service Regional Office | 238 |
| Rogue River - Siskiyou NF - Main Office | 190 |
| Land Between the Lakes | 190 |
| Chugach National Forest | 184 |
| Fremont-Winema NF - Main Office | 151 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 123 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Caribou-Targhee NF - Dubois District | 107 |

**4.0%**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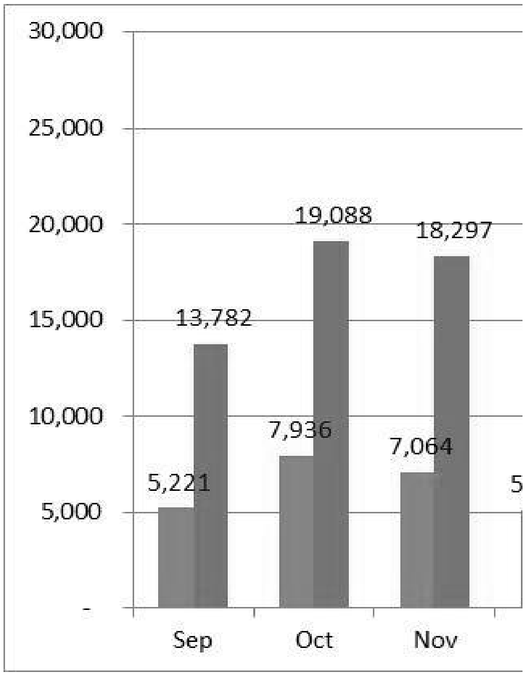
USACE, 2,402
BLM, 2,045
FS, 5,059
NPS, 40,374

**9.9%**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25,000
20,000
15,000
10,000
5,000
-
13,782
19,088
18,297
5,221
7,936
7,064
Sep
Oct
Nov

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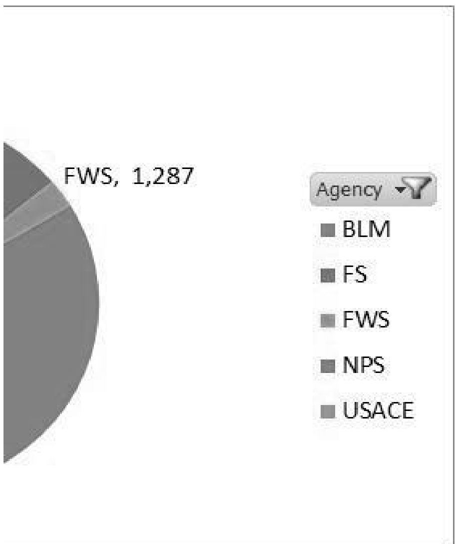


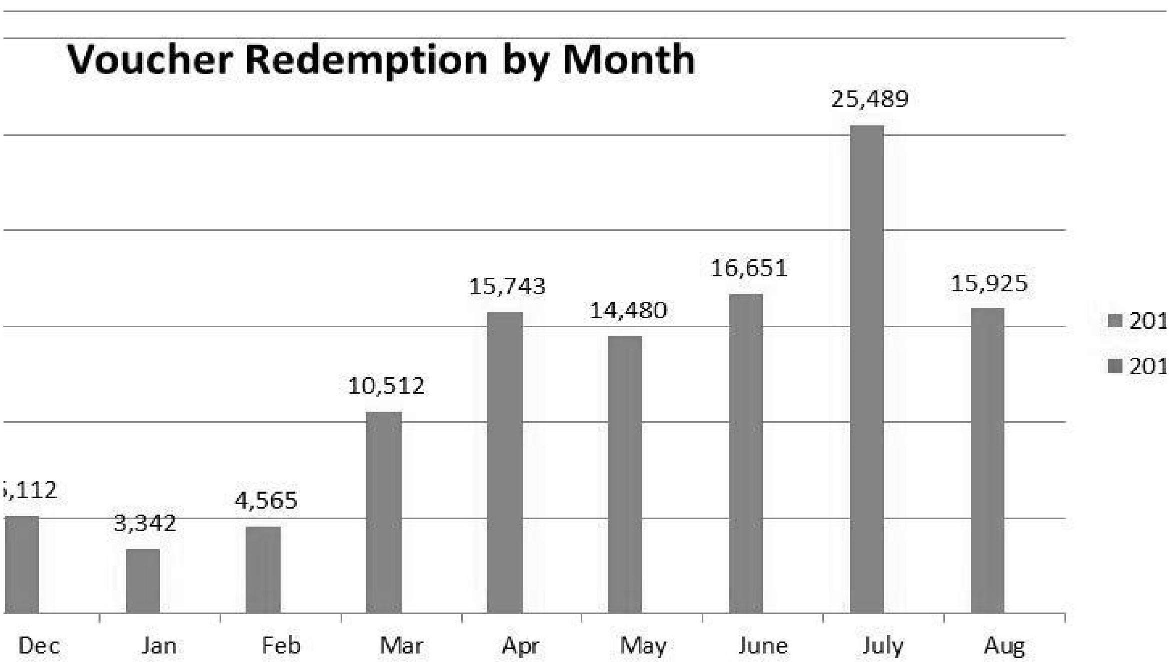

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| l5/2016 |
| l6/2017 |

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|---|---|
| Bighorn NF - Powder River District | 107 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Umpqua NF - Main Office | 71 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 47 |
| Mt Hood NF - Zigzag District | 44 |
| Coconino NF - Red Rock Visitor's Center | 42 |
| Lewis & Clark NF - Main Office | 38 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Pike & San Isabel NF - South Platte District | 33 |
| Gifford Pinchot NF - Mt Adams District | 26 |
| Coconino NF - Red Rock District | 25 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Olympic NF - Main Office | 23 |
| Washington & Jefferson NF - Lee District | 20 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Tonto NF - Mesa District | 16 |
| Tonto NF - Main Office | 16 |
| Coronado NF - Main Office | 14 |
| Shasta-Trinity NF - Main Office | 14 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 13 |
| Sawtooth NF - Fairfield District | 13 |
| Kaibab NF - North Kaibab District | 12 |
| Prescott NF - Bradshaw District | 11 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 10 |
| Bridger-Teton NF - Pinedale District | 9 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 9 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 8 |
| Gifford Pinchot NF - Main Office | 7 |
| Coconino NF - Mogollon Rim District | 6 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 6 |
| Tonto NF - Cave Creek District | 5 |
| Kaibab NF - Main Office | 5 |
| Caribou-Targhee NF - Westside District | 5 |
| White River NF - Dillon District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| Coconino NF - Main Office | 5 |
| Bighorn NF - Medicine Wheel/Paintrock District | 4 |
| Kaibab NF - Williams District | 3 |
| Angeles NF - Main Office | 3 |
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Willamette NF - McKenzie River District | 3 |
| Klamath NF - Main Office | 3 |
| Sawtooth NF - Minidoka District | 3 |
| Prescott NF - Chino District | 3 |

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|---|---|
| Inyo NF - Mammoth Lakes Center | 3 |
| San Juan NF - Dolores District | 2 |
| Sequoia NF - Main Office | 2 |
| Helena NF - Helena District | 2 |
| Colville NF - Newport District | 2 |
| Nez Perce NF - Main Office | 2 |
| Willamette NF - Detroit District | 2 |
| Apache-Sitgreaves NF - Black Mesa District | 2 |
| San Bernardino NF - Main Office | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Caribou-Targhee NF - Palisades District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| Kaibab NF - Tusayan District | 1 |
| Black Hills NF - Main Office | 1 |
| Coronado NF - Douglas District | 1 |
| Black Hills NF - Mystic District | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Sawtooth NF - Stanley District | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Okanogan-Wenatchee NF - Main Office | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Colville NF - Three Rivers District | 1 |
| Klamath NF - Scott River & Salmon River Districts | 1 |
| Croatan NF - Main Office | 1 |
| Payette NF - New Meadows District | 1 |
| Grey Towers National Historic Site | 1 |
| Uinta-Wasatch-Cache NF - Logan District | 1 |
| Humboldt-Toiyabe NF - Carson District | 1 |
| Umatilla NF - Walla Walla District | 1 |
| Santa Fe NF - Main Office | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Sierra NF - Main Office | 1 |
| Cleveland NF - Trabuco District | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Fishlake NF - Beaver District | 1 |
| Sam Houston NF | 1 |
| Mendocino NF - Main Office | 1 |
| San Juan NF - Pagosa District | 1 |
| Payette NF - McCall District | 1 |
| Sawtooth NF - Main Office | 1 |
| Routt NF - Parks Walden District | 1 |
| Deschutes NF - Bend/Fort Rock District | 1 |
| Los Padres NF - Main Office | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |

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17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

| | |
|---|---|
| Six Rivers NF - Mad River District | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| Uinta-Wasatch-Cache NF - Evanston District | 1 |
| White Mountain NF - Saco District | 1 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 1 |
| Tahoe NF - Main Office | 1 |
| **FWS** | **1,287** |
| J.N. "Ding" Darling National Wildlife Refuge | 181 |
| Arthur R. Marshall Loxahatchee NWR | 152 |
| Sam D. Hamilton Noxubee NWR | 146 |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 126 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| St. Marks National Wildlife Refuge | 103 |
| Merritt Island National Wildlife Refuge | 81 |
| Bombay Hook National Wildlife Refuge | 65 |
| DeSoto National Wildlife Refuge | 65 |
| Sacramento NWR | 36 |
| Nisqually NWR | 30 |
| Two Rivers National Wildlife Refuge | 25 |
| Fish and Wildlife Service Regional Office | 18 |
| Chincoteague NWR | 17 |
| Back Bay NWR | 16 |
| National Elk Refuge | 8 |
| Parker River National Wildlife Refuge | 3 |
| Ottawa National Wildlife Refuge | 3 |
| Ridgefield NWRC | 1 |
| **NPS** | **40,374** |
| Assateague Island National Seashore | 4,638 |
| Yosemite National Park | 2,108 |
| Chamizal National Memorial | 1,917 |
| San Juan National Historic Site | 1,645 |
| Colonial National Historical Park | 1,533 |
| Indiana Dunes National Lakeshore | 1,526 |
| Fort McHenry National Monument | 1,346 |
| Chesapeake & Ohio Canal NHP | 1,322 |
| Lake Mead National Recreation Area | 1,307 |
| Hopewell Culture National Historical Park | 1,158 |
| Acadia National Park | 1,132 |
| Cuyahoga Valley National Park | 1,126 |
| Rocky Mountain National Park | 929 |
| Grand Canyon National Park | 881 |
| Zion National Park | 879 |
| Garfield National Historic Site | 876 |
| Yellowstone National Park | 755 |

**2.5%**

**78.9%**

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

| | |
|---|---|
| Cedar Breaks National Monument | 743 |
| Walnut Canyon National Monument | 714 |
| Mount Rainier National Park | 712 |
| Arches National Park | 593 |
| Great Falls Park | 575 |
| Richmond National Battlefield Park | 564 |
| Harpers Ferry National Historical Park | 519 |
| Catoctin Mountain Park | 499 |
| Organ Pipe Cactus National Monument | 466 |
| Blue Ridge Parkway (Campgrounds) | 412 |
| Sequoia & Kings Canyon National Park | 373 |
| Lewis & Clark National Historical Park | 351 |
| Montezuma Castle National Monument | 346 |
| Big South Fork National River & Recreation Area | 313 |
| Olympic National Park | 291 |
| Big Thicket National Preserve | 265 |
| Petroglyph National Monument | 258 |
| San Francisco Maritime National Historical Park | 254 |
| Bryce Canyon National Park | 235 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 229 |
| Joshua Tree National Park | 217 |
| Grand Teton National Park | 215 |
| Shenandoah National Park - Thornton Gap Entrance | 209 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Dinosaur National Monument (Passes only sold at UT location)) | 203 |
| Florissant Fossil Beds National Monument | 191 |
| Wright Brothers National Memorial | 190 |
| Badlands National Park | 186 |
| Fort Washington Park | 177 |
| Crater Lake National Park | 175 |
| Pinnacles National Monument | 170 |
| Shenandoah National Park - Front Royal Entrance | 165 |
| Fossil Butte National Monument | 161 |
| Glacier National Park | 158 |
| Death Valley National Park | 157 |
| Shenandoah National Park - Swift Run Entrance | 157 |
| Casa Grande Ruins National Monument | 155 |
| Lava Beds National Monument | 134 |
| Cabrillo National Monument | 130 |
| Mesa Verde National Park | 121 |
| Jewel Cave National Monument | 120 |
| Castillo de San Marcos National Monument | 114 |
| Bighorn Canyon National Recreation Area | 110 |
| Lassen Volcanic National Park | 109 |
| Colorado National Monument | 106 |

241 from SAAN including 120 from 2015/2016 exchanges

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

| | |
|---|---|
| Fort Vancouver National Historic Site | 103 |
| Carlsbad Caverns National Park | 102 |
| Greenbelt Park | 98 |
| Hot Springs National Park | 95 |
| Hawaii Volcanoes National Park | 91 |
| Everglades National Park | 90 |
| Aztec Ruins National Monument | 89 |
| Canyonlands National Park | 88 |
| Antietam National Battlefield | 78 |
| Craters of the Moon National Monument | 76 |
| Obed Wild and Scenic River | 68 |
| Prince William Forest Park | 65 |
| Mammoth Cave National Park | 64 |
| Shenandoah National Park - Rockfish Entrance | 63 |
| Sleeping Bear Dunes National Lakeshore | 63 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| Klondike Gold Rush National Historical Park | 60 |
| Sunset Crater Volcano National Monument | 58 |
| Little Rock Central High School NHS | 53 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Saguaro National Park | 47 |
| Haleakala National Park | 47 |
| Gulf Islands National Seashore | 45 |
| Big Bend National Park | 40 |
| Wind Cave National Park | 40 |
| Devils Tower National Monument | 39 |
| Saint Gaudens National Historic Site | 37 |
| Weir Farm National Historic Site | 37 |
| Timpanogos Cave National Monument | 36 |
| Golden Spike National Historic Site | 35 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Steamtown National Historic Site | 31 |
| Great Sand Dunes National Park | 30 |
| Fort Union National Monument | 29 |
| Canaveral National Seashore | 24 |
| Lowell National Historical Park | 24 |
| Capitol Reef National Park | 24 |
| Mount Rushmore National Memorial | 22 |
| Padre Island National Seashore | 22 |
| Little Bighorn Battlefield National Monument | 20 |
| Pipestone National Monument | 19 |
| Bandalier National Monument | 18 |
| Theodore Roosevelt National Park - South Unit | 18 |
| Edison National Historical Park | 17 |

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

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| | |
|---|---|
| Saratoga National Historical Park | 17 |
| White Sands National Monument | 17 |
| Whiskeytown National Recreation Area | 16 |
| Denali National Park & Preserve | 16 |
| Vicksburg National Military Park | 15 |
| Pipe Spring National Monument | 14 |
| Scotts Bluff National Monument | 13 |
| Lincoln Boyhood National Memorial | 12 |
| Wilson's Creek National Battlefield | 11 |
| Pu'uhonua O Honaunau | 9 |
| Fort Moultrie National Monument | 9 |
| Chickamauga & Chattanooga National Military Park | 9 |
| Wupatki National Monument | 7 |
| Chickasaw National Recreation Area | 6 |
| Harry S Truman National Historic Site | 6 |
| Tonto National Monument | 5 |
| Great Basin National Park | 5 |
| Herbert Hoover National Historical Site | 4 |
| Johnstown Flood National Memorial | 4 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 4 |
| Tuzigoot National Monument | 4 |
| Channel Islands National Park | 4 |
| Fort Necessity National Battlefield | 4 |
| Gila Cliff Dwellings National Monument | 4 |
| Tumacacori National Historical Park | 3 |
| Chaco Culture National Historical Park | 3 |
| Ulysses S Grant National Historic Site | 3 |
| Fort Davis National Historic Site | 3 |
| Capulin Volcano National Monument | 2 |
| Valles Caldera National Preserve | 2 |
| National Historic Oregon Trail Interpretive Center | 2 |
| Isle Royale National Park | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Mississippi National River & Recreation Area | 2 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| Pictured Rocks National Seashore | 1 |
| **USACE** | **2,402** |
| Philpott Lake | 1,303 |
| Proctor lake | 260 |
| Carters | 174 |
| Woodruff-Seminole | 150 |
| Wappapello Lake | 124 |
| Greers Ferry Lake | 60 |
| Falls Lake | 54 |
| John H. Kerr Dam and Reservoir | 53 |

**4.7%**

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

| | |
|---|---|
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Sandy Lake Recreation Area | 43 |
| Allatoona | 33 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Lake Shelbyville | 3 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| North Hartland Lake | 2 |
| Bay Model Visitor Center | 1 |
| Raystown Lake Project | 1 |
| Abiquiu Lake | 1 |
| Hensley Lake | 1 |
| Table Rock Lake | 1 |

17-01174_010998;17-01174_010998;17-01174_010999;17-01174_011000;17-01174_011001;17-01174_011002;1...

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**To:** Patel, Sandeep (OS/ASA)[Sandeep.Patel@hhs.gov]
**Cc:** Evans, Heather (Fed)[heather.evans@nist.gov]; Nelson, Chris A. EOP/OSTP[redacted] Munoz, Jose L.[jmunoz@nsf.gov]; lynn.buquo@nasa.gov[lynn.buquo@nasa.gov]; Shaw, Denice[Shaw.Denice@epa.gov]; Meador, Jarah[Jarah.Meador@va.gov]; thomas.feucht@usdoj.gov[thomas.feucht@usdoj.gov]; James.Grove@HQ.DHS.GOV[James.Grove@hq.dhs.gov]; Garson, Jennifer[Jennifer.Garson@hq.doe.gov]; Walker, Traci L. EOP/OMB[redacted] phsue@ftc.gov[phsue@ftc.gov]; dpremo@cns.gov[dpremo@cns.gov]; pdavis@cpsc.gov[pdavis@cpsc.gov]; Whitney, Tyson - OCFO[Tyson.Whitney@cfo.usda.gov]; Martin.D.Dubroff@hud.gov[Martin.D.Dubroff@hud.gov]; Grace Hoerner[ghoerner@usaid.gov]; Goklany, Indur[indur_goklany@ios.doi.gov]; Albert.Palacios@ed.gov[Albert.Palacios@ed.gov]; Buquo, Lynn (JSC-SA511)[lynn.buquo-1@nasa.gov]; Daffan, Kathleen[kdaffan@ftc.gov]
**From:** Kelly Olson - TAE
**Sent:** 2016-12-20T00:17:56-05:00
**Importance:** Normal
**Subject:** Re: Agency Prize Leads - Leadership Framing Discussion
**Received:** 2016-12-20T00:18:04-05:00

Thanks for getting this started, Chris. I haven't had an opportunity to work on reframing the common language for challenge.gov specifically but hope that our team can finalize that in early January to share with you. We are working more specifically on GSA and our organization, the Technology Transformation Service (TTS) level messaging. What seems to be resonating there is less about innovation and more about new processes and approaches for business impact, effective streamlined delivery of solutions faster, better, cheaper and creating a citizen-centric government. We will map challenge.gov specific messaging down from here but it will be really helpful to have numbers to accompany the narrative. Examples of cost savings/avoidance $$ by using a challenge v. traditional procurement and examples of measurable impact/results for the public/citizens.

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-Sandeep

Sandeep Patel, PhD
HHS Open Innovation Manager

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From: Evans, Heather (Fed) [mailto:heather.evans@nist.gov]
Sent: Friday, December 16, 2016 3:48 PM
To: Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; lynn.buquo@nasa.gov; Shaw, Denice ; Meador, Jarah ; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Patel, Sandeep (OS/ASA); Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; kelly.olson@gsa.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511); Daffan, Kathleen
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Have a great weekend,
Heather

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In particular, it might be helpful for Kelly to weigh in from the GSA perspective on whether you have common language about the role of Challenge.gov and GSA that would be helpful for everyone to use.

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Thanks so much!
~Chris

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**From:** Evans, Heather (Fed)
**Sent:** 2016-12-20T11:25:02-05:00
**Importance:** Normal
**Subject:** RE: Agency Prize Leads - Leadership Framing Discussion
**Received:** 2016-12-20T11:25:18-05:00

Kelly, thanks so much for this update.

One issue that I really look forward to talking about is the extent to which agencies are going to frame challenges as an "acquisition hack, pay for success acquisition model" – I don't see that working for us, at least certainly not "acquisition hack." We have had lots of philosophical discussions with our legal counsel about the line between stimulating outside players to innovate vs. what has been perceived as a thinly veiled attempt to acquire something that we should otherwise be using the FAR and "traditional" procurement for. I am fairly certain that the latter is not something we have buy-in to do and isn't intrinsically captured by the prize authority language in competes/aica. In any case if the momentum is swinging toward messaging challenges this way, it would be incredibly helpful if the White House/OMB could issue clarifying guidance about using the prize authority to this end, and perhaps also to get general counsel conversations going to try to get them on similar pathways.

The challenge-based acquisition concept is really interesting but so progressive that I am not sure how long it will take to get my agency on board. I haven't mustered the energy to start that conversation yet, but we may do that in the coming year. Look forward to hearing from everyone on that issue as well.

Happy holidays!
Heather

**From:** Kelly Olson - TAE [mailto:kelly.olson@gsa.gov]
**Sent:** Tuesday, December 20, 2016 12:18 AM
**To:** Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov>
**Cc:** Evans, Heather (Fed) <heather.evans@nist.gov>; Nelson, Chris A. EOP/OSTP [redacted] Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB <[redacted] phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>;

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**From:** Grove, James
**Sent:** 2016-12-20T11:52:49-05:00
**Importance:** Normal
**Subject:** RE: Agency Prize Leads - Leadership Framing Discussion
**Received:** 2016-12-20T11:53:00-05:00

I will let you know how we make out at DHS.

Our Procurement Innovation Lab wishes to simplify the Broad Agency Announcement process (referenced at FAR 15 and 35 in the Mitre report) to hopefully attract more submissions, overcome some negative comments from industry etc. I asked that as we assess these changes that we consider the Mitre report and how we might run prize parallel or in conjunction with BAAs for basic and applied research. My assumption is that the prize will advance concepts to the early prototype stage and the BAA process will take it across the finish line. There may be other simultaneous contracting actions but for now this it's a start.

---

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**Sent:** Tuesday, December 20, 2016 11:25 AM
**To:** Kelly Olson - TAE <kelly.olson@gsa.gov>; Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov>
**Cc:** Nelson, Chris A. EOP/OSTP[redacted]; Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; Grove, James <James.Grove@HQ.DHS.GOV>; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB [redacted]; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
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**Sent:** 2016-12-20T16:34:01-05:00
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Thanks, everyone! This is very helpful information and valuable perspectives to bring back to our team a they work on messaging. I'm meeting with a team in the GSA Federal Acquisition Service tomorrow and I'm sure they will have similar views and concerns to those you've shared. The high level points I shared and the reference to an acquisition hack are just initial ideas thrown out by the internal team. I assure you these still need to go through major refinement and check points (including legal) to ensure they are helpful to agency's efforts at the program level. Clarity on using traditional procurement, the FAR and alternative approaches in an acquisition strategy still need to be defined in the new environment. We are a ways off from that. Please continue to share :)
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To: Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Sandeep.Patel@hhs.gov; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB <[redacted] phsue@ftc.gov; kelly.olson@gsa.gov; Evans, Heather (Fed) <heather.evans@nist.gov>; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
Subject: Agency Prize Leads - Leadership Framing Discussion

Hi All:

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In particular, it might be helpful for Kelly to weigh in from the GSA perspective on whether you have common language about the role of Challenge.gov and GSA that would be helpful for everyone to use.

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Thanks so much!
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**From:** Patel, Sandeep (OS/ASA)
**Sent:** 2016-12-20T17:15:20-05:00
**Importance:** Normal
**Subject:** RE: Agency Prize Leads - Leadership Framing Discussion
**Received:** 2016-12-20T17:15:33-05:00

I'm pasting Jim's response in here so we have a single thread with all the responses ☺.

Thanks Chris, Kelly, Heather, Lynn, and Jim for bringing up topics that are also front and center at HHS. What a great conversation so far!

At HHS, we've framed challenges specifically as collaborative problem-solving tools to achieve one or more of three things: (1) procure efficiently, (2) stimulate market activity, and (3) engage with the public. That being said, over 90% of our prize activity has aimed to do the latter two. We haven't run into any legal issue with using challenges as a procurement tool, but it doesn't necessarily seem to be a good tool for it. At least, we haven't used it well enough that way. We share Jim's sentiment of finding prize to procurement strategies (or creative ways to reach broad audiences within the FAR).

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-Sandeep

**From:** Grove, James [mailto:James.Grove@HQ.DHS.GOV]
**Sent:** Tuesday, December 20, 2016 11:53 AM
**To:** Evans, Heather (Fed); Kelly Olson - TAE; Patel, Sandeep (OS/ASA)
**Cc:** Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; lynn.buquo@nasa.gov; Shaw, Denice; Meador, Jarah; thomas.feucht@usdoj.gov; Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511); Daffan, Kathleen
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**Sent:** Tuesday, December 20, 2016 4:56 PM
**To:** Buquo, Lynn (JSC-SA511)
**Cc:** Evans, Heather (Fed); Patel, Sandeep (OS/ASA); Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; Shaw, Denice; Meador, Jarah; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Albert.Palacios@ed.gov; Daffan, Kathleen; Kaminski, Amy P. (HQ-AE000)
**Subject:** Re: Agency Prize Leads - Leadership Framing Discussion

Thanks, everyone! This is very helpful information and valuable perspectives to bring back to our team a they work on messaging. I'm meeting with a team in the GSA Federal Acquisition Service tomorrow and I'm sure they will have similar views and concerns to those you've shared. The high level points I shared and the reference to an acquisition hack are just initial ideas thrown out by the internal team. I assure you these still need to go through major refinement and check points (including legal) to ensure they are helpful to agency's efforts at the program level. Clarity on using traditional procurement, the FAR and alternative approaches in an acquisition strategy still need to be defined in the new environment. We are a ways off from that. Please continue to share :)

Kelly

On Tue, Dec 20, 2016 at 4:34 PM, Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>

wrote:
Agree with Heather because I know our agency legal team submitted comments regarding the language that seemed to suggest a prize competition could be used as an acquisition strategy and they strongly encouraged clarification.

As you know, NASA currently uses procurement authority to launch a challenge, but those challenges are NOT considered NASA prize competitions, they are the vendor's. We are about to conduct our first competition under COMPETES and it has been made crystal clear to me we are not acquiring anything and need to ensure that stays clear.

We, too, will be interested in how this evolves and I would look forward to an opportunity to include our legal folks in a discussion on the subject.

I celebrate the accomplishment of getting new legislation in place and look forward to more conversations in the New Year.

Sent from my iPhone
On Dec 20, 2016, at 11:25 AM, Evans, Heather (Fed) <heather.evans@nist.gov> wrote:

Kelly, thanks so much for this update.

One issue that I really look forward to talking about is the extent to which agencies are going to frame challenges as an “acquisition hack, pay for success acquisition model” – I don’t see that working for us, at least certainly not “acquisition hack.” We have had lots of philosophical discussions with our legal counsel about the line between stimulating outside players to innovate vs. what has been perceived as a thinly veiled attempt to acquire something that we should otherwise be using the FAR and “traditional” procurement for. I am fairly certain that the latter is not something we have buy-in to do and isn’t intrinsically captured by the prize authority language in competes/aica. In any case if the momentum is swinging toward messaging challenges this way, it would be incredibly helpful if the White House/OMB could issue clarifying guidance about using the prize authority to this end, and perhaps also to get general counsel conversations going to try to get them on similar pathways.

The challenge-based acquisition concept is really interesting but so progressive that I am not sure how long it will take to get my agency on board. I haven’t mustered the energy to start that conversation yet, but we may do that in the coming year. Look forward to hearing from everyone on that issue as well.

Happy holidays!
Heather

**From:** Kelly Olson - TAE [mailto:kelly.olson@gsa.gov]
**Sent:** Tuesday, December 20, 2016 12:18 AM
**To:** Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov>

**Cc:** Evans, Heather (Fed) <heather.evans@nist.gov>; Nelson, Chris A. EOP/OSTP <Christofer_A_Nelson@ostp.eop.gov>; Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB [redacted] (b)(6)-White House Staff >; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
**Subject:** Re: Agency Prize Leads - Leadership Framing Discussion

Thanks for getting this started, Chris. I haven't had an opportunity to work on reframing the common language for challenge.gov specifically but hope that our team can finalize that in early January to share with you. We are working more specifically on GSA and our organization, the Technology Transformation Service (TTS) level messaging. What seems to be resonating there is less about innovation and more about new processes and approaches for business impact, effective streamlined delivery of solutions faster, better, cheaper and creating a citizen-centric government. We will map challenge.gov specific messaging down from here but it will be really helpful to have numbers to accompany the narrative. Examples of cost savings/avoidance $$ by using a challenge v. traditional procurement and examples of measurable impact/results for the public/citizens.

Topline Messages:

- TTS is helping the government buy better (challenge.gov has been referred to as an acquisition hack here, pay for success acquisition model rather than "open innovation")

- TTS wants to help government vendors do their best work by helping fix the acquisition process from the inside. (challenge based acquisition/modular contracting has been referred to here)

- All parts of TTS have delivered better digital and IT services for the government, and often collaborate to get the best results for the customer. (collaboration and external/public engagement to drive solution development)

- Our focus is on customer experience, efficiency, cost savings or avoidance, and cybersecurity. (focused on citizen-centric, saving money and security)

The current messaging we've been using has challenge.gov and citizenscience.gov combined as open innovation. We are still undecided

on whether we will keep it that way or separate. Much of that will be determined once we hear some of the early priorities and agenda items of the incoming administration.

Kelly

On Mon, Dec 19, 2016 at 9:52 AM, Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov> wrote:
We at HHS were finalizing our Departmental COMPETES policy revision. Given the forthcoming legislation, we'll revisit the policy to make sure it reflects the statutory changes, including a possible name change (what are we calling this prize authority now??). One big unknown for us now is to what extent we include the new citizen science and crowdsourcing authorities into the same policy. Personally, I'm leaning towards combining them.

-Sandeep

Sandeep Patel, PhD
HHS Open Innovation Manager

-----Original Message-----
From: Evans, Heather (Fed) [mailto:heather.evans@nist.gov]
Sent: Friday, December 16, 2016 3:48 PM
To: Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; lynn.buquo@nasa.gov; Shaw, Denice ; Meador, Jarah ; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Patel, Sandeep (OS/ASA); Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; kelly.olson@gsa.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511); Daffan, Kathleen
Subject: RE: Agency Prize Leads - Leadership Framing Discussion

Chris,

I think this is a great idea. I am also curious if today's House passage of S. 3084 will update agency policies (for those who were using COMPETES, like my agency) and/or make some things easier (one thing will be easier - the OSTP report only every other year! Hah).

Have a great weekend,
Heather

-----Original Message-----
From: Nelson, Chris A. EOP/OSTP [mailto:[redacted] (b)(6)-White House Staff
Sent: Friday, December 16, 2016 3:23 PM

To: Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Sandeep.Patel@hhs.gov; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB [redacted]>; phsue@ftc.gov; kelly.olson@gsa.gov; Evans, Heather (Fed) <heather.evans@nist.gov>; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
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Thanks so much!
~Chris

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**To:** Patel, Sandeep (OS/ASA)[Sandeep.Patel@hhs.gov]; Kelly Olson - TAE[kelly.olson@gsa.gov]; Buquo, Lynn (JSC-SA511)[lynn.buquo-1@nasa.gov]
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**From:** Palacios, Albert
**Sent:** 2016-12-21T10:01:09-05:00
**Importance:** Normal
**Subject:** RE: Agency Prize Leads - Leadership Framing Discussion
**Received:** 2016-12-21T10:01:20-05:00

Hello All,

Just a few bits of kindling for the campfire from my box at ED:

1. We use procurement authority rather than the COMPETES act. We issue logistical contracts to manage our prize competitions which makes a few steps in the process a bit easier.
2. The main reasons we are using challenges are to bring outside solutions from new solvers (not the usual suspects), identify innovative approaches from outside the EdTech market, improve the market for EdTech, and maximize the impact of our very limited budget for innovation.
3. We do not use challenges as a procurement tool, but being in the challenge mindset has caused us to reframe our other procurements so that we are purchasing solutions rather than development of the solutions (especially in IT).
4. While we do acquire solution libraries and portfolios from the challenges, our outcomes are more for the benefit of the public education system rather than the Department.

Ditto on Sandeep’s and Lynn’s comments as well.

Happy Holidays to all and stay warm… unless you are in Florida, then stay cool.

Thanks,
-Albert

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**From:** Patel, Sandeep (OS/ASA) [mailto:Sandeep.Patel@hhs.gov]
**Sent:** Tuesday, December 20, 2016 5:15 PM
**To:** Kelly Olson - TAE; Buquo, Lynn (JSC-SA511)
**Cc:** Evans, Heather (Fed); Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; Shaw, Denice; Meador, Jarah; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Palacios, Albert; Daffan, Kathleen; Kaminski, Amy P. (HQ-AE000)
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**Sent:** Tuesday, December 20, 2016 12:18 AM
**To:** Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov>
**Cc:** Evans, Heather (Fed) <heather.evans@nist.gov>; Nelson, Chris A. EOP/OSTP <[redacted] (b)(6)-White House Staff>; Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB [redacted] (b)(6)-White House Staff>; phsue@ftc.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
**Subject:** Re: Agency Prize Leads - Leadership Framing Discussion

Thanks for getting this started, Chris. I haven't had an opportunity to work on reframing the common language for challenge.gov specifically but hope that our team can finalize that in early January to share with you. We are working more

specifically on GSA and our organization, the Technology Transformation Service (TTS) level messaging. What seems to be resonating there is less about innovation and more about new processes and approaches for business impact, effective streamlined delivery of solutions faster, better, cheaper and creating a citizen-centric government. We will map challenge.gov specific messaging down from here but it will be really helpful to have numbers to accompany the narrative. Examples of cost savings/avoidance $$ by using a challenge v. traditional procurement and examples of measurable impact/results for the public/citizens.

Topline Messages:

- TTS is helping the government buy better (challenge.gov has been referred to as an acquisition hack here, pay for success acquisition model rather than "open innovation")
- TTS wants to help government vendors do their best work by helping fix the acquisition process from the inside. (challenge based acquisition/modular contracting has been referred to here)
- All parts of TTS have delivered better digital and IT services for the government, and often collaborate to get the best results for the customer. (collaboration and external/public engagement to drive solution development)
- Our focus is on customer experience, efficiency, cost savings or avoidance, and cybersecurity. (focused on citizen-centric, saving money and security)

The current messaging we've been using has challenge.gov and citizenscience.gov combined as open innovation. We are still undecided on whether we will keep it that way or separate. Much of that will be determined once we hear some of the early priorities and agenda items of the incoming administration.

Kelly

On Mon, Dec 19, 2016 at 9:52 AM, Patel, Sandeep (OS/ASA) <Sandeep.Patel@hhs.gov> wrote:

> We at HHS were finalizing our Departmental COMPETES policy revision. Given the forthcoming legislation, we'll revisit the policy to make sure it reflects the statutory changes, including a possible name change (what are we calling this prize authority now??). One big unknown for us now is to what extent we include the new citizen science and crowdsourcing authorities into the same policy. Personally, I'm leaning towards combining them.

-Sandeep

Sandeep Patel, PhD
HHS Open Innovation Manager

-----Original Message-----
From: Evans, Heather (Fed) [mailto:heather.evans@nist.gov]
Sent: Friday, December 16, 2016 3:48 PM
To: Nelson, Chris A. EOP/OSTP; Munoz, Jose L.; lynn.buquo@nasa.gov; Shaw, Denice ; Meador, Jarah ; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Patel, Sandeep (OS/ASA); Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; kelly.olson@gsa.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511); Daffan, Kathleen
Subject: RE: Agency Prize Leads - Leadership Framing Discussion

Chris,

I think this is a great idea. I am also curious if today's House passage of S. 3084 will update agency policies (for those who were using COMPETES, like my agency) and/or make some things easier (one thing will be easier - the OSTP report only every other year! Hah).

Have a great weekend,
Heather

-----Original Message-----
From: Nelson, Chris A. EOP/OSTP [mailto:[redacted] (b)(6)-White House Staff
Sent: Friday, December 16, 2016 3:23 PM
To: Munoz, Jose L. <jmunoz@nsf.gov>; lynn.buquo@nasa.gov; Shaw, Denice <Shaw.Denice@epa.gov>; Meador, Jarah <Jarah.Meador@va.gov>; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Sandeep.Patel@hhs.gov; Garson, Jennifer <Jennifer.Garson@hq.doe.gov>; Walker, Traci L. EOP/OMB [redacted] (b)(6)-White House Staff>; phsue@ftc.gov; kelly.olson@gsa.gov; Evans, Heather (Fed) <heather.evans@nist.gov>; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO <Tyson.Whitney@cfo.usda.gov>; Martin.D.Dubroff@hud.gov; Grace Hoerner <ghoerner@usaid.gov>; Goklany, Indur <indur_goklany@ios.doi.gov>; Albert.Palacios@ed.gov; Buquo, Lynn (JSC-SA511) <lynn.buquo-1@nasa.gov>; Daffan, Kathleen <kdaffan@ftc.gov>
Subject: Agency Prize Leads - Leadership Framing Discussion

Hi All:

Thanks to many of you for meeting last week. I am working on scheduling a follow-up meeting for early January that I will get on the calendar in the next day or two.

In the meantime, I wanted to start an email chain about how we're all framing prizes and challenges for incoming leadership. While everyone is working on this, even if it is in draft form, it may be useful to share that framing with others. We can learn from each other's framing, and, where helpful, synchronize messages. Of course, everything shared is internal, deliberative, draft form, and not for distribution.

In particular, it might be helpful for Kelly to weigh in from the GSA perspective on whether you have common language about the role of Challenge.gov and GSA that would be helpful for everyone to use.

Starting the conversation, looking forward to everyone's input.

Thanks so much!
~Chris

Christofer Nelson
Assistant Director for Open Innovation
Office of Science and Technology Policy
Executive Office of the President

--
Kelly Olson
Senior Innovation Advisor
Acting Director, Innovation Portfolio
Technology Transformation Service
U.S. General Services Administration
(202) 297-4522
kelly.olson@gsa.gov

--
Kelly Olson
Senior Innovation Advisor
Acting Director, Innovation Portfolio
Technology Transformation Service
U.S. General Services Administration
(202) 297-4522

kelly.olson@gsa.gov

**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**Cc:** Leslie Richardson[leslie_a_richardson@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-01-02T18:35:36-05:00
**Importance:** Normal
**Subject:** Fwd: Report on Pricing of the Interagency Annual Pass
**Received:** 2017-01-02T18:36:06-05:00
Pricing of the Interagency Annual Pass.docx

Hello everyone,
Leslie Richardson and Christian Crowley have completed the attached review of the Interagency Annual Pass Pricing Study. Thanks Leslie and Christian! I thought it would be benefitial for everyone to take an initial look and discuss on our call.  Thanks!  ...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

---------- Forwarded message ----------
From: **Richardson, Leslie** <leslie_a_richardson@nps.gov>
Date: Fri, Dec 30, 2016 at 7:45 PM
Subject: Report on Pricing of the Interagency Annual Pass
To: "Linford, Brooke" <brooke_linford@nps.gov>
Cc: Christian Crowley <Christian.Crowley@ios.doi.gov>, Benjamin Simon <benjamin_simon@ios.doi.gov>, Bret Meldrum <bret_meldrum@nps.gov>, Lynne Koontz <lynne_koontz@nps.gov>

Hi Brooke,
Christian and I have completed our review of existing data and recommendations for pricing of the Interagency Annual Pass. It is attached. Please let us know if you have any questions, comments or edits. And we would be happy to set up a time to discuss this once you've had a chance to read through it.

We really enjoyed digging into this, so thanks for the opportunity. Happy New Year!
Leslie & Christian

Leslie Richardson

17-01174_011068;17-01174_011068;17-01174_011069

Economist, Social Science Program
National Park Service
leslie_a_richardson@nps.gov
970-267-7313

# Pricing of the Interagency Annual Pass: A Review of Existing Data and Analyses

Leslie Richardson[1] and Christian Crowley[2]

[1]Economist, National Park Service, Social Science Program, leslie_a_richardson@nps.gov, 970-267-7313

[2]Economist, Department of the Interior, Office of Policy Analysis, christian_crowley@ios.doi.gov, 202-208-3799

## Contents

## Executive Summary


The Interagency Annual Pass, which provides access to more than 2,000 federal recreation sites that charge an entrance fee or other day use fee, has been available at a price of $80 since 2007. The goal of this effort was to evaluate various sources of existing data and analyses to help inform potential changes in the price of the Annual Pass. Specifically, we looked at recent reviews and audits, agency revenues and pass sales, entrance and other site access fees, and a 2006 pricing analysis of the Interagency Annual Pass, which was updated in this report using current pass sales data.

Key findings indicate that a modest increase in the price of the Interagency Annual Pass may be warranted for the following reasons:

- The price of the pass has never been adjusted for inflation, meaning in real dollars, the pass is more than 10% cheaper than it was when it was introduced in 2007.
- As noted in the University of Wyoming's 2006 Interagency Annual Pass pricing study, whatever base price is chosen for the pass could be adjusted upward in advance to account for future increases in entrance fees. In reality, entrance fees at NPS sites have increased more than 40% since 2014, whereas the Interagency Annual Pass has remained at $80 since 2007.
- Based on an evaluation of NPS recreation fee and revenue changes over time, it appears that park visitation is relatively unresponsive to increases in entrance and other site access fees. A similar finding can be gleaned from our update of the University of Wyoming's 2006 pricing analysis. As a result, increasing the price of the Interagency Annual Pass by $5 or $10 is not expected to greatly reduce demand or pass revenues, and it should serve to increase total revenues and reduce 'foregone' revenues in aggregate across all agencies participating in the pass program.

Of course, numerous objectives have to be balanced when evaluating the price of the Interagency Annual Pass. For instance, a higher price is likely to increase total revenues, but may discourage visitation to federal lands relative to a lower pass price, especially if entrance fees also continue to increase. This raises questions of what represents a 'fair' pass price, in terms of maintaining affordable access to federal recreation sites. In addition, it was beyond the scope of this study to evaluate any indirect effects of increasing the price of the pass (such as reduced visitor crowding), or the distributional effects of pricing changes on individual agencies. Finally, this effort evaluated existing data and analyses only. A new comprehensive study of the Interagency Annual Pass could be undertaken to determine people's satisfaction with the current pass, assess their motivations for buying the pass, and conduct a more accurate and updated pricing analysis.

## Introduction

In 2007, the Interagency Annual Pass, also referred to as the "America the Beautiful – the National Parks and Federal Recreational Lands Pass," was made available to the public, replacing the Golden Eagle and National Parks Passes. The pass covers entrance and standard amenity fees at federal recreation sites managed by the National Park Service, Fish and Wildlife Service, the Forest Service, Bureau of Land Management, Bureau of Reclamation, and the U.S. Army Corps of Engineers. In selecting a price for the pass, the goal was to charge a price that made sense in economic terms, was defensible and understandable to decision makers and the public, and would not cause total revenues across all agencies to be less than total revenues in the absence of the pass program. In addition, the price should take into account people's willingness-to-pay for the convenience of using the pass and any altruistic motives they may have. An economic analysis conducted by the University of Wyoming (described in greater detail below) was used to help select a price for the Interagency Annual Pass. Ultimately, the price was set at $80 in 2007 and has not changed since.

Now that the pass has been available for ten years, various sources of existing data can be evaluated and updated to help inform potential changes in the price of the pass. For instance, national park visitors typically have three ways to access sites that charge a day use fee: use the Interagency Annual Pass, pay the daily entrance fee, or use an annual pass that covers entrance to that particular park only. Although the price of the Interagency Annual Pass has not changed, looking at changes in the price of the other two 'substitutes' can provide some insight into how responsive visitors are to price changes. In addition, the University of Wyoming's 2006 pricing analysis can be updated using recent sales data for the Interagency Annual Pass. The overall goal of this effort is to provide information from multiple sources to help policymakers evaluate alternative prices for the pass.

The remainder of this report is outlined as follows. First, background information is provided, including the history of fees under FLREA, history of the Interagency Pass, a summary of the University of Wyoming's 2006 pricing analysis, as well as a summary of recent reports on NPS recreation revenues. Next, an analysis of agency-level revenue, visitation, and entrance fee data is provided. An update to the University of Wyoming's 2006 pricing analysis is then presented, followed by recommendations for future study.

# Background

Federal recreation sites in the United States annually host hundreds of millions of visitors, including for 2015:

- 370 million visits to Army Corps of Engineers areas;[1]
- 307 million visits to National Park Service sites;[2]
- 188 million estimated visits to National Forest System sites;[3]
- 62 million estimated visits to Bureau of Land Management sites;[4]
- 48 million estimated visits to National Wildlife Refuges;[5] and
- 28 million estimated visits to Reclamation sites.[6]

Recreation facilities and opportunities at many of these sites are funded in part by visitors, through revenue collected under the Federal Lands Recreation Enhancement Act (FLREA). FLREA revenue, in the form of on-site fees and pass sales, is an important funding source for federal lands management, along with Congressional appropriations, donations, rents, commercial use fees, etc.

## History of Fees under FLREA

The National Recreation Fee Demonstration Program was created in 1996 as a three-year pilot program. This was followed by FLREA in 2004. Under FLREA federal land management agencies are authorized to collect fees from visitors, and to use those fees to develop and maintain public recreation sites. Participating agencies include the Department of the Interior's (DOI's) Bureau of Land Management (BLM), Bureau of Reclamation (Reclamation), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS); and the U.S. Department of Agriculture's (USDA's) Forest Service (USFS). The U.S. Army Corps of Engineers (USACE) was authorized to join the FLREA pass program in the 2014 Water Resources Reform and Development Act.[7]

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[1] Annual average, from http://www.usace.army.mil/Missions/Civil-Works/Recreation/
[2] NPS Annual Visitation Summary Report for 2015 https://irma.nps.gov/Stats/SSRSReports/National%20Reports/Annual%20Visitation%20Summary%20Report%20(1979%20-%20Last%20Calendar%20Year)
[3] https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf
[4] BLM Public Land Statistics, FY 2015, Table 4-1. https://www.blm.gov/public_land_statistics/pls15/pls2015.pdf
[5] DOI data.
[6] DOI data
[7] Since the enactment of FLREA, interagency passes have been accepted at certain sites managed by the U.S. Army Corps of Engineers (USACE) and Tennessee Valley Authority.

FLREA authorizes the agencies to charge several types of fees:

- NPS and FWS charge *entrance fees* at sites like National Parks and Wildlife Refuges;
- BLM, USFS, and Reclamation charge *standard amenity recreation fees* at sites like picnic areas and interpretive sites;
- Agencies collect *expanded amenity recreation fees* for enhanced services such as a cabin rental, campgrounds, and boat launch facilities; and
- *Special Recreation Permits* for activities such as off-highway vehicle use, guiding, and events.

In deciding whether to establish or change fees at federally managed sites, the agencies engage with the public and stakeholders to ensure that the different perspectives are considered and that the fees are appropriate. Fees are currently charged at about 45% of NPS sites, 32% of USFS sites, 7% of FWS refuges, for 1% of BLM acreage, and a single Reclamation site. FLREA fee revenue has increased steadily from $196 million in Fiscal Year (FY) 2005 to $278 million in FY 2014 (DOI and USDA, 2015).

## NPS Entrance Fees

McKinsey & Co (2001) completed a study of NPS entrance fees finding that prices were not standardized across the nation. The authors recommended developing a national model to determine prices. In 2006, NPS implemented a model starting at 34 NPS units. NPS sites were divided into four groups, based on type of site and visitation levels:

- Group 4 includes the nine most-visited parks (Bryce, Glacier, Grand Canyon, Grand Teton, Rocky Mountain, Sequoia-Kings, Yellowstone, Yosemite, Zion);
- Group 3 includes all other National Parks;
- Group 2 includes the more visited non-Park unit-types (e.g., Seashores, Monuments);
- Group 1 includes the less visited non-Park unit-types (e.g. National Battlefields, Parkways)

In 2008 the National economy entered a recession, and NPS implemented a moratorium on increasing fees. In 2014, NPS lifted the moratorium and started applying fee increases using the updated pricing structure shown in Table 1. Proposed fees are subject to public review and comment through the “civic engagement” process. Proposed fees are reviewed by the Executive Committee and must be approved by the NPS National Leadership Council (NLC).

Table 1. National Park Service Entrance Fees (2014 Update)

| Group | Site Types | Annual Pass | Per Vehicle | Per Person | Motor-cycle |
|---|---|---|---|---|---|
| 1 | National Historic Sites, National Military Parks, National Battlefield Parks, National Memorials/Shrines, National Preserves, and Parkways | $30 | $15 | $7 | $10 |
| 2 | National Seashores, National Recreation Areas, National Monuments, National Lakeshores, and National Historic Parks | $40 | $20 | $10 | $15 |
| 3 | National Parks | $50 | $25 | $12 | $20 |
| 4 | National Parks | $60 | $30 | $15 | $25 |
| | Increase over 2006 Fees | $10 | $5 | $2,$3 | $5 |

Sources: DOI and USDA (2015); GAO (2015)

## History of the Interagency Pass

Prior to FLREA, various federal recreation sites accepted a variety of passes, including the Golden Eagle Passport, Golden Age Passport, Golden Access Passports, and the National Parks Pass. FLREA authorized a new interagency pass family called the "America the Beautiful - National Parks and Federal Recreational Lands Passes." Passes are sold at participating recreation sites, over the phone or online at websites like store.usgs.gov (so-called *central sales*), at third-party vendors (e.g., outdoors outfitters), and at certain agency offices. The agencies currently offer a variety of interagency passes accepted at FLREA sites around the country:

- An $80 Annual Pass;
- A $10 lifetime Senior Pass for those 62 and older;[8]
- A free Every Kid in a Park Pass for 4th graders;
- A free Access Pass for those with permanent disabilities;
- A free Annual Military Pass for members of the military and their families; and

[8] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20.

- A free Volunteer Pass for those who volunteer 250 hours on public lands.

The agencies also have occasional fee-free days for the general public.

FLREA requires the agencies to report to Congress every three years on implementation of the recreation fee program. The 2015 Triennial Report shows that pass sales have continued to increase, up to nearly one million passes annually. Of these, about two-thirds are for the $10 Senior Pass, and one-third are for the $80 Annual Pass. As shown in Table 2, over 80 percent of sales are made at NPS sites, with a further 8 or 9 percent of the total sold at USFS sites.

Table 2. Proportion of Interagency Passes Sold, by Agency and Pass Type

| | FY 2012 | FY 2012 | FY 2013 | FY 2013 | FY 2014 | FY 2014 |
|---|---|---|---|---|---|---|
| NPS pass sales | 763,124 | 81% | 792,062 | 82% | 798,683 | 80% |
| USFS pass sales | 84,093 | 9% | 80,298 | 8% | 81,007 | 8% |
| Pass Types (All Agencies) | | | | | | |
| Annual Passes | 314,835 | 34% | 329,530 | 34% | 356,016 | 36% |
| Senior Passes | 624,540 | 66% | 641,703 | 66% | 637,015 | 64% |
| Total Passes | 939,375 | | 971,233 | | 993,031 | |

Source: DOI and USDA (2015)

There was a dramatic increase in pass sales in FY 2015, leading up to the 2016 NPS Centennial. In FY 2015, NPS sites saw a 33 percent increase in the level of Annual Passes sold, compared to FY 2014. USFS sites saw a similar increase in Senior Passes sold over the same period (though only a 4 percent increase for Annual Passes), and FWS reported a 25% increase in all Interagency Passes sold. Central and third party sales saw an increase of over 45 percent (though these sources typically make up about 2 percent of pass sales).[9]

Pass-holders gain free entry to many recreational sites managed by federal agencies, however there is no centralized tracking system available to determine where and when the passes are used. In 2016 NPS published “The National Parks and Federal Recreational Lands Pass Survey,” reporting the results of a survey of pass use among pass-holders who purchased a pass through central sales via the USGS website

[9] Data from DOI and USDA, in personal communications.

(rather than in person, at a recreation site). The repeat contact mail survey had a final response rate of 43.5%, with 772 completed surveys returned.

The survey asked respondents to recall the last five times they had used their pass to access a recreation site.[10] Overall, approximately 85% of pass use was reported to be at NPS sites, and about 8% at USFS sites. Reclamation, BLM, and USFWS sites saw 2% or less of reported pass uses (Bioeconomics, 2016).

## Summary of the University of Wyoming's 2006 Pricing Analysis

In 2005, the U.S. Department of Agriculture and the Department of the Interior issued a request for proposals to evaluate possible prices for the new Interagency Annual Pass. A project proposal submitted by the University of Wyoming, through its Wyoming Survey and Analysis Center, was selected to provide the requested assistance. The project consisted of five main tasks:

1. The production of a roadmap detailing the steps that would be taken to complete the remaining tasks;
2. A benchmarking study used to compare existing federal recreation passes with state and Parks Canada passes;
3. An examination of theoretical and methodological issues in the economics of non-market valuation;
4. Focus groups; and
5. A national telephone survey.

The overall goal of the project was to provide information from multiple sources that could assist policymakers in determining a price for the new Interagency Annual Pass. The national telephone survey in particular provided comprehensive information on the number of households that would be expected to purchase the pass at various prices. This information was then used to forecast revenues from the sale of the pass, as well as gate revenues, across all agencies at various pass prices. In addition, the request for proposals stipulated that the price of the pass "should at least allow the government to break even in the sense that, on average, the sale of the pass does not result in a loss of revenue relative to the revenue that would be received absent the ability to purchase an annual pass." To address this, the researchers also evaluated foregone revenue (total revenues in the absence of the pass program minus total revenues with

[10] The survey also asked about 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

the pass program) at various pass prices. They determined that the price of the pass would need to be set at $125 or above to come close to revenue neutrality, assuming gate entrance fees remained at their current level. At the time of the study, $125 was equal to the cost of an annual pass for California's state parks, and was less than the price of an annual pass for Parks Canada. A novel addition to their analysis was the use of Golden Eagle and National Parks Pass sales data to calibrate hypothetical willingness-to-pay values with real choices. Now that the Interagency Annual Pass has been available for the last ten years, this calibration can be updated using current data on the number of passes sold at a price of $80. This will provide some indication of how pass sales and associated revenues might be expected to change at different pass prices. The details of this analysis are presented later in this report.

### Recent Reports on NPS Recreation Revenues

This section focuses on the National Park Service, though the conclusions are generally applicable across all FLREA agencies. GAO (2015) found that total funding for the National Park Service (NPS) has not kept pace with inflation in recent years, making FLREA revenue an increasingly important part of total NPS funding. Recognizing this increasing importance, GAO recommended that NPS periodically review entrance fees for potential updates. GAO also recommended amendments to FLREA so that the federal agencies can adjust pass prices, in particular the $10 lifetime Senior Pass.

OIG (2015) examined opportunities for the National Park Service (NPS) to increase its recreation program revenues, focusing on the three largest sources of recreation revenues: park-unit entrance fees, interagency passes, and commercial bus tour fees. OIG recommended that NPS establish intervals for periodic reviews to ensure that prices for these three revenue sources remain up to date. In particular, OIG recommended updating the price of the $80 Annual Pass.[11]

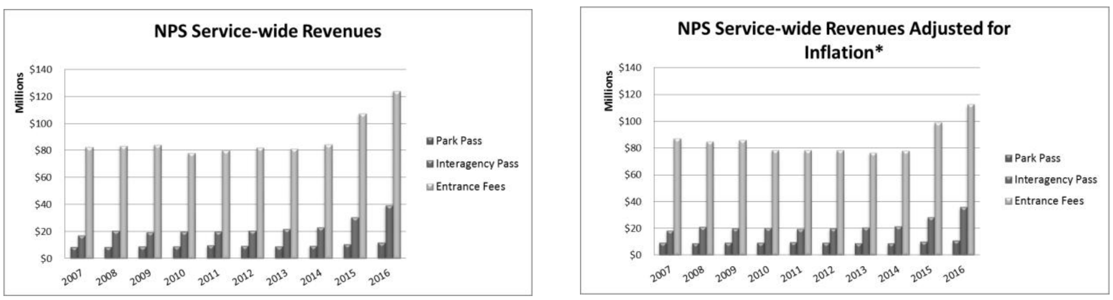
## Agency-level Study

We reviewed data on FLREA revenues collected by the agencies in recent years. This section focuses mainly on NPS, as the agency that had the most robust data available. Service-wide revenues from the sale of individual park passes, the Interagency Annual Pass, and daily admission/entrance fees from 2007-2016 are shown in Figure 1 (data are preliminary for 2016). Since these revenues occur in different years, the figure on the right shows revenues adjusted for inflation. In general, revenues from all sources have seen large increases since 2014, both in nominal dollars and after adjustment for inflation. Revenue from

[11] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20.

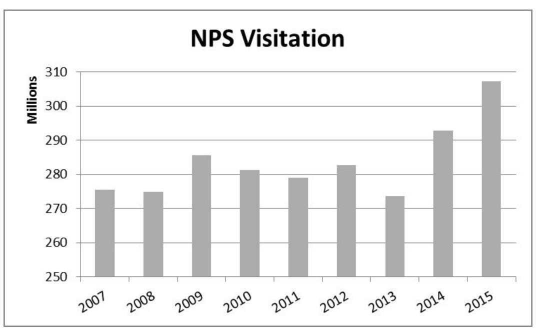
the sale of individual park passes has increased by about 25% since 2014, revenue from the sale of the Interagency Annual Pass has increased by nearly 70% since 2014, and revenue from entrance fees has increased by about 45% since 2014. This boost in revenues is partly due to increased visitation to NPS sites (Figure 2), which could be related to the 2016 NPS Centennial. Although finalized 2016 visitation data are not yet available, many parks are already reporting record-breaking visitation.

Figure 1. NPS Service-wide Revenues, in Nominal and Real Dollars, 2007-2016



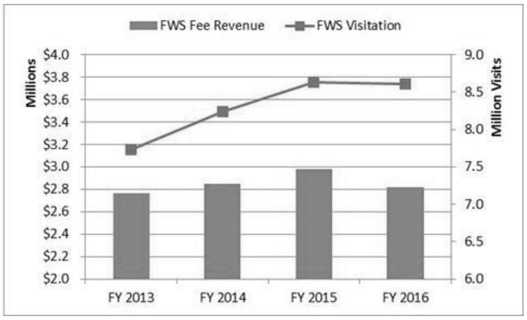

*Adjusted for inflation using the Bureau of Labor Statistics Consumer Price Index; base year is 2010

Figure 2. NPS Visitation, 2007-2015



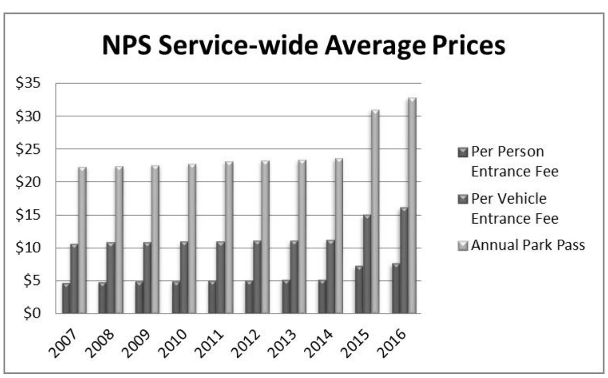

Data for FY 2013 through FY 2015 show that FWS visitation and fee revenues followed a similar pattern to that of NPS, though with a less dramatic increase in FY 2015 (Figure 3). However, in FY 2016 FWS saw a drop in fee revenues, as opposed to NPS's continued increase.

Figure 3. FWS Fee Revenue and Visitation, FY13-FY16




In addition to trends in total revenues and visitation, prices represent another important piece of information. Although the price of the Interagency Annual Pass has remained at $80, park entrance fees and the prices of annual individual park passes have changed over time, especially after the moratorium on fee increases was lifted in 2014. For those parks that charge an entrance fee, Figure 4 shows the average per-vehicle and per-person entrance fee charged from 2007 to 2016, as well as the average price of an annual individual park pass for those parks that offer such passes. Over that time period, per-vehicle entrance fees have increased by more than 50% on average (30% when adjusted for inflation), and per-person entrance fees have increased by about 60% (40% when adjusted for inflation). Just since 2014, per-vehicle and per-person entrance fees have increased by more than 40% on average. The average price of an individual park pass has increased by about 45% since 2007 (25% when adjusted for inflation) and by more than 35% since 2014.

Figure 4. Average Per-Vehicle Entrance Fee, Per-Person Entrance Fee, and Individual Park Pass Price at NPS Sites, 2007-2016



There are two important takeaways from this review of NPS recreation fees and revenues over time:

- At the system-wide level, park visitation appears to be relatively unresponsive to price increases associated with site access. There have been large increases in the average price of entrance fees and individual park passes, especially since 2014, and revenues across all sources have continued to increase, both in nominal and real dollars. This is consistent with previous findings that entrance fees alone are not a barrier to more frequent visitation of NPS units (Ostergren et al., 2005; Factor, 2007). Of course, entrance and other site access fees typically represent only a small portion of the total trip cost that must be considered when making the decision to visit a park.
- The University of Wyoming's 2006 pricing analysis for the Interagency Annual Pass (discussed in greater detail below) highlighted the fact that whatever base price was ultimately chosen for the pass could be adjusted in advance to account for future increases in gate fees. They explain that while the pass might realistically see cost of living adjustments every three years or so, gate fees could increase more often than that. Assuming that average gate fees increase by 10% over a three-year period, the Interagency Annual Pass would need to include a 10% premium at the outset to ensure that it satisfies revenue neutrality. In reality, while entrance fees across the National Park System have increased significantly over the last few years, the price of the Interagency Annual Pass has remained at $80.

## Updating the University of Wyoming's 2006 Pricing Analysis

In 2006, researchers at the University of Wyoming completed an analysis to assist with pricing of the new Interagency Annual Pass (hereafter referred to as Aadland and Shogren, 2006). The basis of the analysis was a nationwide telephone survey administered to two independent strata: a nationally representative sample of U.S. households obtained through random digit dialing (RDD sample) and a random sample of households known to the National Park Foundation to have purchased a National Parks Pass between April 2004 and March 2005, which included mainly those households that purchased the pass online (NPF sample). The analysis is based on the assumption that an individual household will choose to buy the new Interagency Annual Pass if the benefits of doing so outweigh the costs. It is initially assumed that the primary motivation for purchasing the pass is based solely on its economic value; that is, people will purchase the pass if it reduces their expected costs associated with visitation to federal recreation sites. The policymaker's decision is to choose the price of the pass to maintain revenue neutrality; i.e., total

revenues across all agencies participating in the pass program will not be less than total revenues in the absence of the pass program.

To determine how much respondents would be willing to pay for the new Interagency Annual Pass, the study used a nonmarket valuation method known as Contingent Valuation (CV). After a short description of the new pass, households that had visited federal recreation lands in the last two years were presented with a dichotomous choice CV question in which they were asked if they would be willing to purchase the pass at a randomly selected price, ranging from $25 to $165. After responding 'yes' or 'no,' they were asked a follow-up CV question to more precisely determine their actual willingness-to-pay for the pass. If the respondent answered 'no' to the first price, they were presented with a lower price and asked if they would be willing to purchase the pass. If the respondent answered 'yes' to the first price, they were presented with a higher price and asked if they would be willing to purchase the pass. Using the results from this series of questions and scaling to the relevant population of potential pass purchasers, Aadland and Shogren (2006) were able to project the number of households that would be expected to purchase the pass at various prices. To do so, they rely on two different estimates:

1. Unconditional estimates – these estimates do not rely on any econometric model, but rather, are derived directly from households' responses to the two CV questions. For example, if a respondent said 'yes' to a pass price of $65, but 'no' to a pass price of $85, their true willingness-to-pay is assumed to be the midpoint of this interval, or $75. If a respondent said 'yes' to a pass price of $65 and 'yes' to a pass price of $85, they are assigned a willingness-to-pay value of the high price plus $10, or $95 in this example. Finally, if a respondent said 'no' to a pass price of $65 and 'no' to a pass price of $45, they are assigned a willingness-to-pay value equal to half of the lower price, or $22.50.

2. Conditional estimates – these estimates are derived from an econometric model, specifically, an interval regression model. There is a probability associated with each household's possible series of responses to the two CV questions – yes/yes, no/no, yes/no, and no/yes. These probabilities are used to create a log likelihood function, and the regression coefficients are then chosen to maximize this function. Predicted willingness-to-pay estimates for every household in the sample can then be calculated based on these results.

As with any application of the Contingent Valuation Method, survey respondents are asked to make a hypothetical purchasing decision. However, since they are not actually required to pay what they say they

will, respondents may overstate their willingness-to-pay. To address this possible hypothetical bias, Aadland and Shogren (2006) used outside information on real market transactions to 'calibrate' their projected demand estimates. Specifically, revenues from the sale of the National Parks Pass and the Golden Eagle Pass were used to scale the projected Interagency Annual Pass revenues (and number of pass-holders, which is just total revenue divided by price) in an effort to better reflect the actual purchasing decisions of consumers. Now that we have ten years of sales data for the Interagency Annual Pass at a price of $80, we can use this information to update the external calibration for hypothetical bias and more accurately capture current demand for the pass. Across all agencies, sales of the Interagency Annual Pass from 2009 to 2014 were as follows:

Table 3. Interagency Annual Passes Sold by Year and by Agency

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| BLM | 2,434 | 2,765 | 3,874 | 3,858 | 4,267 | 6,348 |
| FWS | 1,667 | 1,771 | 1,922 | 1,819 | 2,014 | 1,926 |
| NPS | 243,281 | 259,580 | 251,779 | 262,678 | 276,824 | 290,035 |
| BOR | 29 | 48 | 56 | 62 | 161 | 20 |
| USFS | 18,287 | 18,329 | 18,469 | 18,537 | 17,557 | 20,871 |
| Central Sales | 21,300 | 22,178 | 18,942 | 16,948 | 18,363 | 23,360 |
| Third Party | 3,144 | 6,387 | 7,842 | 10,933 | 10,344 | 13,456 |
| Total | 290,142 | 311,058 | 302,884 | 314,835 | 329,530 | 356,016 |

Based on the last three years that data are available, total Annual Pass sales have averaged around 333,460 per year at a pass price of $80. This price/quantity point is used to calibrate the unconditional and conditional demand estimates from Aadland and Shogren (2006). For instance, if their estimates predicted that there would be 450,000 passes demanded at a price of $80, but we know there were only 333,460 passes sold at a price of $80, then we divide the number of predicted passes demanded at each price by a factor of 1.35 (450,000/333,460). This is essentially shifting the entire demand curve to more accurately project the number of passes that could be expected to be sold at various prices. We focus on the RDD sample only since the NPF sample accounts for a very small and specific group of pass purchasers from 2006. As noted by Aadland and Shogren (2006), if the two samples were combined and weighted to reflect their relative population sizes, the combined results would be virtually indistinguishable from an analysis of the RDD sample alone.

As with most goods bought and sold in the marketplace, as the price of the pass increases, the quantity of passes demanded will decrease, all else constant. The extent of this decrease depends on how responsive people are to price changes, a relationship known as the *price elasticity of demand*. For a particular good, this elasticity is calculated as the percentage change in quantity demanded divided by the percentage change in price. An elasticity less than one in absolute value shows that demand is inelastic – that is, people are relatively unresponsive to price changes, and the percent change in quantity demanded is less than the percent change in price. In this case, revenues (price times quantity sold) will increase as the price increases; additional revenues from people who continue to purchase the pass is greater than the loss in revenue from those who no longer purchase the pass. Conversely, an elasticity greater than one in absolute value shows that demand is elastic – that is, people are more responsive to price changes, and the percent change in quantity demanded is greater than the percent change in price. In this case, revenues will decrease as the price increases; additional revenues from people who continue to purchase the pass do not make up for the loss in revenue from those who no longer purchase the pass due to the higher price.

Using updated calibration factors based on current sales data, we estimate the projected number of pass-holders, price elasticity of demand, and pass revenue (in aggregate across all agencies) for both the unconditional and conditional estimates at various pass prices. These results are shown in Table 4. Based on the unconditional estimates, people are relatively unresponsive to small increases in the price of the pass from the current price of $80 up to about $95. Thus, we see an increase in pass revenue as the pass price increases from $80 up to $95. Beyond that, the estimates predict large decreases in the number of passes sold and therefore, a decrease in pass revenue. The conditional estimates tell a different story - people are relatively responsive to price increases, resulting in a loss in pass revenue as the pass price increases beyond $80. It should be noted that Aadland and Shogren (2006) put more confidence in the unconditional estimates compared to the conditional estimates. This is due to the fact that the econometric model used to generate the conditional estimates tended to do a better job of predicting willingness-to-pay for households on the low end of the willingness-to-pay distribution than on the high end. Because of the poorer fit at the high end, the model tends to incorrectly predict that households will not purchase the pass at high prices (resulting in larger elasticities at high pass prices). Given the difference in the two estimates, we also estimated an econometric model based on households' responses to the first CV question only (ignoring responses to the follow-up question), as the literature has found some evidence of internal inconsistency between responses to the first and second CV questions (Bateman et al., 2001; Cameron and Quiggin, 1994). The results of this model fell between the unconditional and conditional estimates, but aligned more closely with the unconditional estimates. These results predict that demand is

inelastic at price increases from $80 up to about $90 (with pass revenue of $26.6 million), but once the pass price hits around $95 and beyond, demand becomes elastic and pass revenues begin to drop.

Table 4. Projected Number of Pass-holders, Price Elasticity of Demand, and Pass Revenue at Pass Prices of $60 to $120

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders |
| $60 | 561,233 | | 33.7 | 549,228 | | 33.0 |
| $65 | 403,684 | -3.37 | 26.2 | 509,998 | -0.86 | 33.1 |
| $70 | 399,840 | -0.12 | 28.0 | 451,152 | -1.50 | 31.6 |
| $75 | 391,843 | -0.28 | 29.4 | 353,075 | -3.04 | 26.5 |
| $80 | 333,460* | -2.23 | 26.7* | 333,460* | -0.83 | 26.7* |
| $85 | 320,559 | -0.62 | 27.2 | 274,614 | -2.82 | 23.3 |
| $90 | 310,986 | -0.51 | 28.0 | 235,384 | -2.43 | 21.2 |
| $95 | 308,664 | -0.13 | 29.3 | 215,768 | -1.50 | 20.5 |
| $100 | 279,888 | -1.77 | 28.0 | 196,153 | -1.73 | 19.6 |
| $105 | 273,065 | -0.49 | 28.7 | 176,538 | -2.00 | 18.5 |
| $110 | 206,735 | -5.10 | 22.7 | 156,922 | -2.33 | 17.3 |
| $115 | 189,974 | -1.78 | 21.8 | 137,307 | -2.75 | 15.8 |
| $120 | 189,507 | -0.06 | 22.7 | 137,307 | 0.00 | 16.5 |

*actual

NB: Shading indicates inelastic portions of the demand curve (estimated elasticity of demand less than 1.0 in absolute value).

Next we calculate projected gate revenues at various Interagency Annual Pass prices, following the approach taken by Aadland and Shogren (2006). Each household has a particular willingness-to-pay for the pass, and the most they should be willing to pay for the pass is the amount they expect to spend at the gate for all sites they plan to visit that year. They will purchase the pass if their willingness-to-pay is greater than or equal to the price of the pass. If their willingness-to-pay is less than the price of the pass,

they won't purchase the pass, but it is assumed that they will pay their exact willingness-to-pay in gate entrance fees at various recreation sites. For example, say the pass costs $80 but a household is only willing to pay $60 for it. Since their willingness-to-pay is less than the price of the pass, they will not purchase it, but may instead visit a park that charges a $20 entrance fee three times in one year, or alternatively, they may visit a site that charges a $10 entrance fee six times in one year, spending their exact $60 willingness-to-pay to access federal recreation sites. This approach assumes that households do not systematically over or underestimate the expected number of trips to federal recreation sites, and that the decision to purchase the pass is based solely on its economic value. Therefore, at a particular pass price, total gate revenue is calculated by summing willingness-to-pay for all households with willingness-to-pay less than the price of the pass, scaled to the relevant population. Table 5 shows projected pass revenue, gate revenue, and total revenue (pass revenue + gate revenue) at pass prices ranging from $60 to $120. These estimates are calibrated for hypothetical bias, and again, represent totals across all agencies participating in the pass program. The unconditional estimates show pass revenue increasing as the price of the pass increases from the current price of $80 up to about $95, and gate revenues and total revenues continue to increase as the price of the pass increases. The conditional estimates show pass revenue decreasing at prices beyond $80, but gate revenues and total revenues steadily increase as the price of the pass increases.

Table 5. Projected Pass Revenue, Gate Revenue and Total Revenue (Pass+Gate) at Pass Prices of $60 to $120

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) |
| $60 | 33.7 | 181.1 | 214.7 | 33.0 | 213.8 | 246.8 |
| $65 | 26.2 | 191.5 | 217.8 | 33.1 | 216.3 | 249.5 |
| $70 | 28.0 | 191.8 | 219.8 | 31.6 | 220.2 | 251.8 |
| $75 | 29.4 | 192.4 | 221.8 | 26.5 | 227.2 | 253.7 |
| $80 | 26.7* | 194.2 | 220.8 | 26.7* | 228.8 | 255.4 |
| $85 | 27.2 | 195.0 | 222.3 | 23.3 | 233.6 | 256.9 |
| $90 | 28.0 | 195.9 | 223.9 | 21.2 | 236.9 | 258.1 |
| $95 | 29.3 | 197.7 | 227.0 | 20.5 | 238.7 | 259.2 |
| $100 | 28.0 | 199.4 | 227.4 | 19.6 | 240.6 | 260.2 |
| $105 | 28.7 | 199.9 | 228.5 | 18.5 | 242.6 | 261.1 |
| $110 | 22.7 | 208.2 | 230.9 | 17.3 | 244.7 | 262.0 |
| $115 | 21.8 | 209.0 | 230.9 | 15.8 | 246.8 | 262.6 |
| $120 | 22.7 | 209.0 | 231.8 | 16.5 | 246.8 | 263.3 |

*actual

Finally, we calculate foregone revenue, again following the approach taken by Aadland and Shogren (2006). Foregone revenue is simply total revenues in the absence of the pass program minus total revenues with the pass program. Setting the price of the pass in a way that doesn't sacrifice substantial revenues (in aggregate across all agencies) would require foregone revenue to approach zero. This would imply that the program is revenue neutral. Total revenues with the pass program are shown in the previous table. To estimate total revenues in the absence of the pass program, we simply sum willingness-to-pay for every household in the sample, and scale it to the relevant population. This assumes that, if a household does not have the option to purchase the Interagency Annual Pass, they will simply spend their exact willingness-to-pay for the pass on gate entrance fees at federal recreation sites. Estimates of foregone revenue at various pass prices, also calibrated for hypothetical bias, are shown in Table 6. Under

both the unconditional and conditional estimates, foregone revenue is predicted to continue to decrease as the price of the pass increases.

Table 6. Projected Foregone Revenue at Pass Prices of $60 to $120

| | Unconditional Estimates | Conditional Estimates |
|---|---|---|
| Pass Price | Foregone Revenue (millions of dollars) | Foregone Revenue (millions of dollars) |
| $60 | 27.1 | 21.3 |
| $65 | 25.4 | 18.6 |
| $70 | 23.6 | 16.3 |
| $75 | 21.4 | 14.3 |
| $80 | 18.8 | 12.6 |
| $85 | 17.9 | 11.1 |
| $90 | 16.6 | 10.0 |
| $95 | 16.4 | 8.9 |
| $100 | 13.6 | 7.8 |
| $105 | 12.1 | 6.9 |
| $110 | 10.1 | 6.1 |
| $115 | 9.9 | 5.4 |
| $120 | 7.9 | 4.7 |

In summary, based on the analysis outlined in Aadland and Shogren (2006), which has been updated using recent sales data, increasing the price of the Interagency Annual Pass from the current price of $80 is expected to result in increased total revenues (and thus decreased foregone revenues) across all agencies participating in the pass program. Further, based on the unconditional estimates, small increases in the price of the Interagency Annual Pass are not expected to greatly reduce demand, meaning revenue from the sale of the pass may also increase if it's sold at a slightly higher price.

This analysis has assumed that people's motivation for buying the pass is based on economic considerations alone - that is, they will buy the pass if it reduces their expected costs associated with visitation to federal recreation sites. This is a realistic assumption given that the majority of survey

respondents agreed that "the price of the pass compared to the cost of entrance fees" is an important reason to purchase the pass. This was also the primary motivation reported by the Biometrics (2016) survey of central-sales pass purchasers. However, if people are motivated to purchase the pass for other reasons, such as the convenience of not having to make separate entrance fee payments at each site or because they view the pass as a means to maintain and enhance federal lands and facilities, then foregone revenues would be lower at every price point.

Lastly, it is important to note that although the results from Aadland and Shogren (2006) have been updated using current sales data, they are still based on responses to a survey that was conducted more than a decade ago. People now have ten years of experience using the Interagency Annual Pass. A new study would be required to determine whether this experience, or any other factors, have impacted people's motivations for buying the pass or caused potential pass purchasers to be more or less responsive to price changes than indicated by the results presented here.

## Recommendations for Future Study

There are various reasons that program managers may want to consider conducting a new study of the Interagency Annual Pass. The most recent economic analysis used to assist in pricing of the pass was completed more than ten years ago, and many changes have occurred since then. The Annual Pass is no longer a hypothetical good, and the public now has a decade of experience and familiarity with it. The pass itself has evolved over time. For instance, it provides access to additional federal recreation sites that have been designated since 2006, and recreation sites managed by the U.S. Army Corps of Engineers are now included in the program. In addition, population and per capita income have increased in the last ten years, and many federal recreation sites now charge higher entrance fees. Any of these factors have the potential to affect people's motivations for purchasing the pass and the amount that they are willing to pay for it.

It may also be worth developing data on prices of alternatives, such as entrance fees and pass prices for State parks, or Parks Canada. For example, California's State parks pass is now priced at $195. A total of 36 States appear to offer an annual pass, and a further 7 States have no charge for visiting State parks.[12] It may also be worth collecting data on entrance fees at other types of substitute activities (e.g., amusement parks). A broader study could look at how entrance fees figure into travel planning; this would inform estimates of sensitivity to price changes. An area offering the potential for general improvements for

[12] http://usparks.about.com/od/usstateparks/tp/State-Park-Passes.htm

managing recreation lands is improving visitation estimates. For example, NPS Visitor Use Statistics and the USFS National Visitor Use Model offer rigorous approaches that could be adopted at other agencies.

For a better understanding of the mechanics of revenue neutrality, it could be useful to study the effect of recreation price changes on site conditions, both directly (via maintenance budgets) and indirectly (via visitation levels). A review of the interaction between prices, visitation, and site conditions (e.g., resource conditions, crowding, required maintenance, etc.) at federal and State sites could prove informative as FLREA agencies review their pricing policies. Walls (2016) suggests that seasonal prices are an effective way to address crowding and to deal with maintenance requirements that increase with visitation.

If it is determined that a comprehensive study of the Interagency Annual Pass is warranted, a new pricing analysis could provide updated and more accurate information on: 1. The expected number of Interagency Passes sold and associated revenues at various prices (i.e., the demand curve); 2. The sensitivity of passes demanded to price changes (i.e., the price elasticity of demand); 3. The price of the pass required to maintain revenue neutrality, if that is determined to be a goal. A survey-based economic valuation method similar to the one outlined in Aadland and Shogren (2006) would most likely be used to obtain this information. It would be worthwhile to survey a random sample of U.S. households, as well as households known to have purchased the Interagency Annual Pass.

In addition to the economic analysis, a detailed evaluation of people's motivations for buying the pass could be undertaken to complement the findings in the survey of centrally sold pass purchasers (Bioeconomics, 2016).[13] These motivations can affect total revenues as well as foregone revenues at various pass prices, as shown in Aadland and Shogren (2006). Additional survey questions similar to those used in the central-sales survey could be included to determine other information that would be useful to the interagency pass program, such as people's satisfaction with the current Interagency Pass and the effectiveness of marketing techniques. Detailed discussions with program managers would be necessary to determine the specific goals of such a study. A comprehensive study would most likely require survey development, focus groups, and OMB approval, and would take approximately 18-24 months to complete. Additional funding would be required for a contractor to assist DOI/NPS with this effort.

[13] The Bioeconomics survey covered a variety of topics, including 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-01-05T12:29:12-05:00
**Importance:** Normal
**Subject:** December 4th Grade Pass Redemption Report
**Received:** 2017-01-05T12:30:34-05:00
EKIP Redemption Data 9-1-2016 - 12-31-2016.xlsx

Attached is the latest 4th Grade Pass Redemption Report. Pass issuance continues to be strong with an overall increase of 151% over last year at this time. Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 12/31/2016**

**FOR INTERNAL USE ONLY**

| | |
|---|---|
| **Grand Total** | **63,710** |
| **BLM** | **3,000** |
| California BLM Office | 716 |
| Red Rock Canyon National Conservation Area BLM | 402 |
| Eagle Lake BLM Field Office | 351 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| Klamath Falls Resource Area | 189 |
| National Historic Trails Interpretive Center | 171 |
| BLM Eastern States Office | 163 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Redding BLM Field Office | 83 |
| Nevada BLM Office | 83 |
| Red Rock Canyon National Conservation Area - BLM | 79 |
| Coos Bay BLM District Office | 69 |
| Rio Puerco BLM Field Office | 59 |
| BLM Medford Office | 54 |
| Colorado BLM Office | 18 |
| Miles City BLM Office | 13 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Gunnison Gorge National Conservation Area | 9 |
| Utah BLM Office | 4 |
| Royal Gorge BLM Field Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Spokane BLM Office | 2 |
| Eugene District BLM Office | 1 |
| Rock Springs Field Office - BLM | 1 |
| Arizona BLM State Office | 1 |
| **FS** | **6,346** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Stanislaus NF - Mi-Wok District | 500 |
| Lincoln NF - Sacramento District | 397 |
| US Forest Service Region 9 | 331 |
| Umpqua NF - Main Office | 330 |
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Fremont-Winema NF - Main Office | 240 |
| US Forest Service Regional Office | 238 |

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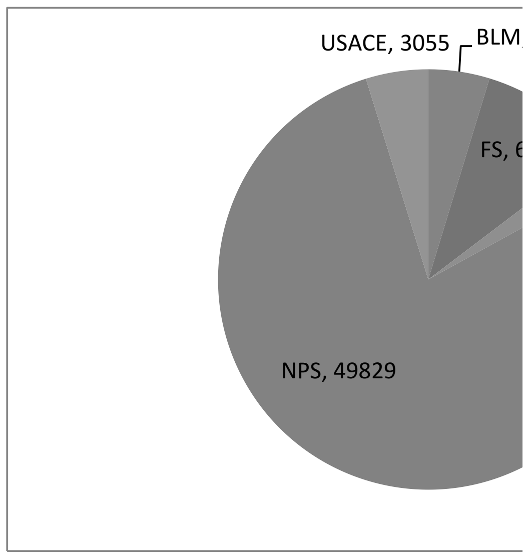


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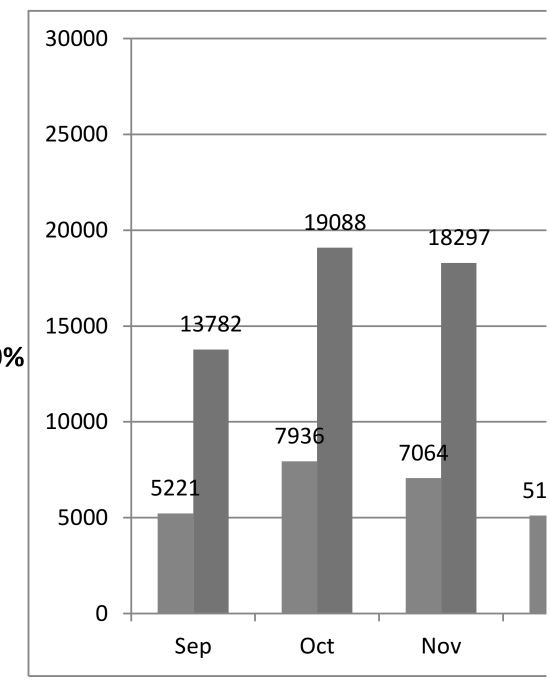

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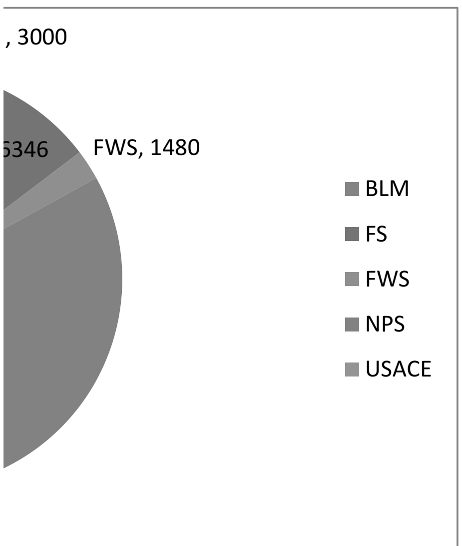


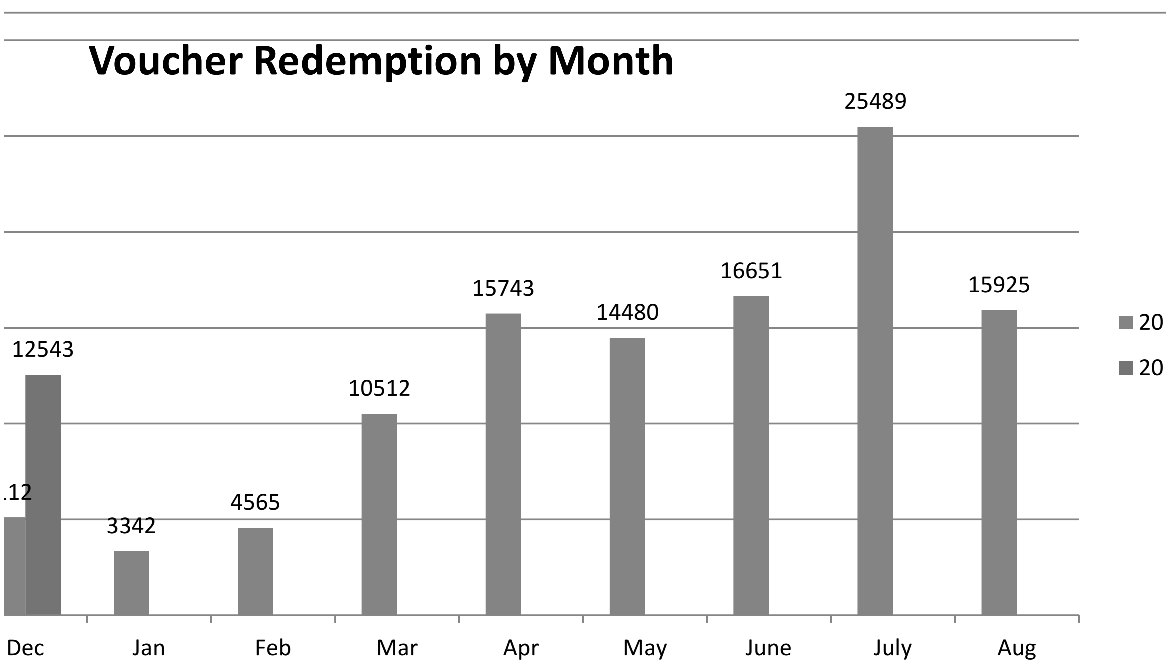

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| | |
|---|---|
| Rogue River - Siskiyou NF - Main Office | 192 |
| Land Between the Lakes | 190 |
| Chugach National Forest | 184 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 133 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Caribou-Targhee NF - Dubois District | 107 |
| Bighorn NF - Powder River District | 107 |
| Umpqua NF - Diamond Lake Visitor Center | 106 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Carson NF - Main Office | 71 |
| Malheur NF - Emigrant Creek District | 67 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Clearwater NF - Main Office | 55 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 53 |
| Mt Hood NF - Zigzag District | 53 |
| Umpqua NF - North Umpqua District | 51 |
| Coconino NF - Red Rock Visitor's Center | 50 |
| Lewis & Clark NF - Main Office | 47 |
| Colville NF - Republic District | 40 |
| Pike & San Isabel NF - South Platte District | 35 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Bighorn NF - Main Office | 30 |
| Coconino NF - Red Rock District | 29 |
| Olympic NF - Main Office | 28 |
| Black Hills NF - Mystic District | 28 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 28 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| Shasta-Trinity NF - Main Office | 27 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Tonto NF - Main Office | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |
| Tonto NF - Mesa District | 20 |
| Washington & Jefferson NF - Lee District | 20 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 19 |
| Carson NF - El Rito Station | 17 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Fishlake NF - Fillmore District | 17 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Sequoia NF - Main Office | 17 |
| Coronado NF - Main Office | 16 |
| Prescott NF - Bradshaw District | 15 |

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| | |
|---|---|
| Humboldt-Toiyabe NF - Main Office | 15 |
| Kaibab NF - North Kaibab District | 15 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Sawtooth NF - Fairfield District | 13 |
| Caribou-Targhee NF - Westside District | 12 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 11 |
| Tonto NF - Cave Creek District | 11 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Santa Fe NF - Main Office | 11 |
| Sawtooth NF - Main Office | 9 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 8 |
| Six Rivers NF - Mad River District | 8 |
| Idaho Panhandle NF - Coeur d'Alene River District | 8 |
| Fishlake NF - Main Office | 8 |
| Black Hills NF - Main Office | 8 |
| Manti-La Sal NF - Main Office | 8 |
| Gifford Pinchot NF - Main Office | 7 |
| Humboldt-Toiyabe NF - Bridgeport District | 7 |
| Kaibab NF - Williams District | 7 |
| Coconino NF - Mogollon Rim District | 6 |
| Sawtooth NF - Minidoka District | 6 |
| Fishlake NF - Fremont River District | 6 |
| San Bernardino NF - San Jacinto District | 5 |
| Kaibab NF - Main Office | 5 |
| Coconino NF - Main Office | 5 |
| Flathead NF - Tally Lake District | 5 |
| Bighorn NF - Medicine Wheel/Paintrock District | 5 |
| White River NF - Dillon District | 5 |
| Prescott NF - Chino District | 4 |
| Colville NF - Newport District | 4 |
| Willamette NF - McKenzie River District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Payette NF - McCall District | 3 |
| Crooked River National Grasland | 3 |
| Klamath NF - Main Office | 3 |
| Angeles NF - Main Office | 3 |
| Okanogan-Wenatchee NF - Cle Elum District | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Okanogan-Wenatchee NF - Main Office | 3 |
| Uinta-Wasatch-Cache NF - Evanston District | 3 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| Mt Hood NF - Clackamas River District | 3 |
| Malheur NF - Main Office | 3 |

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| | |
|---|---|
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Inyo NF - Mammoth Lakes Center | 3 |
| Nez Perce NF - Main Office | 2 |
| Fishlake NF - Beaver District | 2 |
| Green Mountain NF - Middlebury Station | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| San Juan NF - Dolores District | 2 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 2 |
| Willamette NF - Detroit District | 2 |
| Idaho Panhandle NF - Main Office | 2 |
| Helena NF - Helena District | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| San Bernardino NF - Main Office | 2 |
| Coronado NF - Douglas District | 2 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Sawtooth NF - Ketchum District | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| Tahoe NF - Main Office | 1 |
| Six Rivers NF - Orleans District | 1 |
| Umatilla NF - Main Office | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| Ottawa NF - Visitor Center | 1 |
| Gallatin NF - Hebgen Lake District | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Uinta-Wasatch-Cache NF - Logan District | 1 |
| Croatan NF - Main Office | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Colville NF - Three Rivers District | 1 |
| Rogue River - Siskiyou NF - Gold Beach District | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| Siuslaw NF - Main Office | 1 |
| Los Padres NF - Main Office | 1 |
| San Juan Public Lands Center - FS | 1 |
| Mendocino NF - Main Office | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Beaverhead-Deerlodge NF - Main Office | 1 |
| Sam Houston NF | 1 |
| Sierra NF - Main Office | 1 |
| Umpqua NF - Cottage Grove District | 1 |
| White Mountain NF - Saco District | 1 |

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| | |
|---|---|
| Green Mountain NF - Main Office | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Umatilla NF - Walla Walla District | 1 |
| Payette NF - New Meadows District | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Routt NF - Parks Walden District | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Kaibab NF - Tusayan District | 1 |
| Sawtooth NF - Stanley District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |
| Rogue River - Siskiyou NF - Wild Rivers District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Cleveland NF - Trabuco District | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| San Juan NF - Pagosa District | 1 |
| Grey Towers National Historic Site | 1 |
| **FWS** | **1,480** |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 250 |
| Arthur R. Marshall Loxahatchee NWR | 203 |
| J.N. "Ding" Darling National Wildlife Refuge | 182 |
| Sam D. Hamilton Noxubee NWR | 146 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| St. Marks National Wildlife Refuge | 103 |
| Merritt Island National Wildlife Refuge | 83 |
| Bombay Hook National Wildlife Refuge | 65 |
| DeSoto National Wildlife Refuge | 65 |
| Nisqually NWR | 38 |
| Sacramento NWR | 36 |
| Two Rivers National Wildlife Refuge | 25 |
| Fish and Wildlife Service Regional Office | 18 |
| Chincoteague NWR | 17 |
| Back Bay NWR | 16 |
| National Elk Refuge | 9 |
| Don Edwards San Francisco Bay NWR | 6 |
| Parker River National Wildlife Refuge | 3 |
| Ottawa National Wildlife Refuge | 3 |
| Ridgefield NWRC | 1 |
| **NPS** | **49,829** |
| Assateague Island National Seashore | 4,640 |
| Colonial National Historical Park | 3,233 |
| Yosemite National Park | 2,240 |
| Chamizal National Memorial | 2,132 |

2.3%

78.2%

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| | |
|---|---|
| San Juan National Historic Site | 1,933 |
| Chesapeake & Ohio Canal NHP | 1,673 |
| Indiana Dunes National Lakeshore | 1,620 |
| Mount Rainier National Park | 1,604 |
| Fort McHenry National Monument | 1,604 |
| Hopewell Culture National Historical Park | 1,515 |
| Lake Mead National Recreation Area | 1,494 |
| Cuyahoga Valley National Park | 1,273 |
| Acadia National Park | 1,133 |
| Grand Canyon National Park | 1,096 |
| Richmond National Battlefield Park | 1,081 |
| Rocky Mountain National Park | 963 |
| Garfield National Historic Site | 923 |
| Zion National Park | 879 |
| Petroglyph National Monument | 806 |
| Yellowstone National Park | 797 |
| Joshua Tree National Park | 768 |
| Cedar Breaks National Monument | 743 |
| Walnut Canyon National Monument | 733 |
| Arches National Park | 712 |
| Catoctin Mountain Park | 683 |
| Great Falls Park | 663 |
| Colorado National Monument | 612 |
| Harpers Ferry National Historical Park | 519 |
| Organ Pipe Cactus National Monument | 466 |
| Sequoia & Kings Canyon National Park | 415 |
| Blue Ridge Parkway (Campgrounds) | 412 |
| Montezuma Castle National Monument | 386 |
| Olympic National Park | 368 |
| Lewis & Clark National Historical Park | 358 |
| Big South Fork National River & Recreation Area | 313 |
| San Francisco Maritime National Historical Park | 304 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 302 |
| Bryce Canyon National Park | 295 |
| Wright Brothers National Memorial | 294 |
| Big Thicket National Preserve | 265 |
| Everglades National Park | 235 |
| Petrified Forest National Park | 232 |
| Death Valley National Park | 230 |
| Grand Teton National Park | 215 |
| Shenandoah National Park - Thornton Gap Entrance | 212 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Casa Grande Ruins National Monument | 204 |
| Dinosaur National Monument (Passes only sold at UT location)) | 203 |
| Florissant Fossil Beds National Monument | 196 |

241 from SAAN including 120 from 2015/2016 exchanges

91 entered by BISC on 12/7

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| | |
|---|---|
| Pinnacles National Monument | 195 |
| Tonto National Monument | 192 |
| Badlands National Park | 186 |
| Hawaii Volcanoes National Park | 180 |
| Fort Washington Park | 178 |
| Crater Lake National Park | 175 |
| Shenandoah National Park - Front Royal Entrance | 168 |
| Castillo de San Marcos National Monument | 167 |
| Fossil Butte National Monument | 161 |
| Glacier National Park | 159 |
| Shenandoah National Park - Swift Run Entrance | 157 |
| Cabrillo National Monument | 153 |
| Carlsbad Caverns National Park | 137 |
| Lava Beds National Monument | 134 |
| Delaware Water Gap National Rec Area | 133 |
| Mesa Verde National Park | 125 |
| Pu'uhonua O Honaunau | 120 |
| Jewel Cave National Monument | 120 |
| Bighorn Canyon National Recreation Area | 112 |
| Lassen Volcanic National Park | 111 |
| Fort Vancouver National Historic Site | 105 |
| Little Rock Central High School NHS | 103 |
| Canyonlands National Park | 100 |
| Greenbelt Park | 98 |
| Hot Springs National Park | 95 |
| Aztec Ruins National Monument | 90 |
| Sleeping Bear Dunes National Lakeshore | 89 |
| Chickamauga & Chattanooga National Military Park | 88 |
| Saguaro National Park | 79 |
| Antietam National Battlefield | 78 |
| Craters of the Moon National Monument | 76 |
| Prince William Forest Park | 69 |
| Mammoth Cave National Park | 69 |
| Obed Wild and Scenic River | 68 |
| Shenandoah National Park - Rockfish Entrance | 63 |
| Haleakala National Park | 62 |
| Big Bend National Park | 61 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| Klondike Gold Rush National Historical Park | 60 |
| Sunset Crater Volcano National Monument | 58 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Gulf Islands National Seashore | 49 |
| Devils Tower National Monument | 40 |
| Wind Cave National Park | 40 |

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| | |
|---|---|
| Weir Farm National Historic Site | 37 |
| Saint Gaudens National Historic Site | 37 |
| Golden Spike National Historic Site | 36 |
| Timpanogos Cave National Monument | 36 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Steamtown National Historic Site | 33 |
| Bandalier National Monument | 32 |
| White Sands National Monument | 30 |
| Great Sand Dunes National Park | 30 |
| Fort Union National Monument | 29 |
| Canaveral National Seashore | 28 |
| Capitol Reef National Park | 24 |
| Lowell National Historical Park | 24 |
| Mount Rushmore National Memorial | 22 |
| Padre Island National Seashore | 22 |
| Little Bighorn Battlefield National Monument | 20 |
| Pipestone National Monument | 19 |
| Theodore Roosevelt National Park - South Unit | 18 |
| Vicksburg National Military Park | 18 |
| Edison National Historical Park | 17 |
| Scotts Bluff National Monument | 17 |
| Saratoga National Historical Park | 17 |
| Whiskeytown National Recreation Area | 16 |
| Denali National Park & Preserve | 16 |
| Pipe Spring National Monument | 15 |
| Fort Davis National Historic Site | 14 |
| Lincoln Boyhood National Memorial | 13 |
| Fort Moultrie National Monument | 12 |
| Wilson's Creek National Battlefield | 11 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| Great Basin National Park | 7 |
| Wupatki National Monument | 7 |
| Chickasaw National Recreation Area | 6 |
| Tuzigoot National Monument | 6 |
| Harry S Truman National Historic Site | 6 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 6 |
| Natural Bridges National Monument | 5 |
| Ulysses S Grant National Historic Site | 5 |
| Fort Necessity National Battlefield | 4 |
| Herbert Hoover National Historical Site | 4 |
| Channel Islands National Park | 4 |
| Johnstown Flood National Memorial | 4 |
| Gila Cliff Dwellings National Monument | 4 |
| Chaco Culture National Historical Park | 3 |
| Tumacacori National Historical Park | 3 |

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| | |
|---|---|
| Carl Sandburg Home National Historic Site | 3 |
| Isle Royale National Park | 2 |
| Capulin Volcano National Monument | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Valles Caldera National Preserve | 2 |
| National Historic Oregon Trail Interpretive Center | 2 |
| Mississippi National River & Recreation Area | 2 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| Pictured Rocks National Seashore | 1 |
| **USACE** | **3055** |
| Philpott Lake | 1325 |
| Mississippi River Project | 486 |
| Proctor lake | 260 |
| Wappapello Lake | 180 |
| Carters | 174 |
| Woodruff-Seminole | 150 |
| Greers Ferry Lake | 60 |
| Englebright Lake | 58 |
| Falls Lake | 54 |
| John H. Kerr Dam and Reservoir | 53 |
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Sandy Lake Recreation Area | 43 |
| Allatoona | 33 |
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Lake Shelbyville | 5 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| North Hartland Lake | 2 |
| Bay Model Visitor Center | 1 |
| Cowanesque Lake Project | 1 |
| Abiquiu Lake | 1 |
| Raystown Lake Project | 1 |
| Tioga-Hammond Lakes Project | 1 |
| Hensley Lake | 1 |
| Table Rock Lake | 1 |

**4.8%**

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-01-17T09:41:02-05:00
**Importance:** Normal
**Subject:** Fwd: Report on Pricing of the Interagency Annual Pass
**Received:** 2017-01-17T09:41:35-05:00
Pricing of the Interagency Annual Pass 2017-01-13.docx

Hello everyone,
Attached is the revised pass pricing study report. Christian and Leslie will be joining us on our call this afternoon to discuss.  Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

---------- Forwarded message ----------
From: **Richardson, Leslie** <leslie_a_richardson@nps.gov>
Date: Fri, Jan 13, 2017 at 6:49 PM
Subject: Report on Pricing of the Interagency Annual Pass
To: Brooke Linford <brooke_linford@nps.gov>
Cc: Christian Crowley <Christian.Crowley@ios.doi.gov>

Hi Brooke,
Christian and I made a few edits to the report based on our last call, mainly including additional information for the other agencies. An updated version is attached. Have a great weekend!
Leslie

Leslie Richardson
Economist, Social Science Program
National Park Service
leslie_a_richardson@nps.gov
970-267-7313

# Pricing of the Interagency Annual Pass: A Review of Existing Data and Analyses

Leslie Richardson[1] and Christian Crowley[2]

[1]Economist, National Park Service, Social Science Program, leslie_a_richardson@nps.gov, 970-267-7313

[2]Economist, Department of the Interior, Office of Policy Analysis, christian_crowley@ios.doi.gov, 202-208-3799

## Contents

## Executive Summary

The Interagency Annual Pass, which provides access to more than 2,000 federal recreation sites that charge an entrance fee or other day use fee, has been available at a price of $80 since 2007. The goal of this effort was to evaluate various sources of existing data and analyses to help inform potential changes in the price of the Annual Pass. Specifically, we looked at recent reviews and audits, agency revenues and pass sales, entrance and other site access fees, and a 2006 pricing analysis of the Interagency Annual Pass, which was updated in this report using current pass sales data.

Key findings indicate that a modest increase in the price of the Interagency Annual Pass may be warranted for the following reasons:

- If the Interagency Annual Pass were adjusted for inflation, the pass that cost $80 in 2007 would cost about $93 in 2016. The price of the pass has never been adjusted for inflation, meaning in real dollars, the pass is more than 10% cheaper than it was when it was introduced.
- As noted in the University of Wyoming's 2006 Interagency Annual Pass pricing study, whatever base price is chosen for the pass could be adjusted upward in advance to account for future increases in entrance fees. In reality, entrance fees at NPS sites increased by more than 40% once the moratorium on fee increases was lifted in 2014 (equivalent to a 3 to 5 percent increase per year since 2007), whereas the Interagency Annual Pass has remained at $80 since 2007.
- Based on an evaluation of recreation fee and revenue changes over time, it appears that park visitation is relatively unresponsive to increases in entrance and other site access fees. A similar finding can be gleaned from our update of the University of Wyoming's 2006 pricing analysis. As a result, increasing the price of the Interagency Annual Pass up to $90 or $95 is not expected to greatly reduce demand or pass revenues, and it should serve to increase total revenues and reduce 'foregone' revenues in aggregate across all agencies participating in the pass program.

Of course, numerous objectives have to be balanced when evaluating the price of the Interagency Annual Pass. For instance, a higher price is likely to increase total revenues, but may discourage visitation to federal lands relative to a lower pass price, especially if entrance fees also continue to increase. This raises questions of what represents a 'fair' pass price, in terms of maintaining affordable access to federal recreation sites. In addition, it was beyond the scope of this study to evaluate any indirect effects of increasing the price of the pass (such as reduced visitor crowding), or the distributional effects of pricing changes on individual agencies. Finally, this effort evaluated existing data and analyses only. A new comprehensive study of the Interagency Annual Pass could be undertaken to determine people's

satisfaction with the current pass, assess their motivations for buying the pass, and conduct a more accurate and updated pricing analysis.

## Introduction

In 2007, the Interagency Annual Pass, also referred to as the "America the Beautiful – the National Parks and Federal Recreational Lands Pass," was made available to the public, replacing the Golden Eagle and National Parks Passes. The pass covers entrance and standard amenity fees at federal recreation sites managed by the National Park Service, Fish and Wildlife Service, the Forest Service, Bureau of Land Management, Bureau of Reclamation, and the U.S. Army Corps of Engineers. In selecting a price for the pass, the goal was to charge a price that made sense in economic terms, was defensible and understandable to decision makers and the public, and would not cause total revenues across all agencies to be less than total revenues in the absence of the pass program. In addition, the price should take into account people's willingness-to-pay for the convenience of using the pass and any altruistic motives they may have. An economic analysis conducted by the University of Wyoming (described in greater detail below) was used to help select a price for the Interagency Annual Pass. Ultimately, the price was set at $80 in 2007 and has not changed since.

Now that the pass has been available for ten years, various sources of existing data can be evaluated and updated to help inform potential changes in the price of the pass. For instance, national park visitors typically have three ways to access sites that charge a day use fee: use the Interagency Annual Pass, pay the daily entrance fee, or use an annual pass that covers entrance to that particular park only. Although the price of the Interagency Annual Pass has not changed, looking at changes in the price of the other two 'substitutes' can provide some insight into how responsive visitors are to price changes. In addition, the University of Wyoming's 2006 pricing analysis can be updated using recent sales data for the Interagency Annual Pass. The overall goal of this effort is to provide information from multiple sources to help policymakers evaluate alternative prices for the pass.

The remainder of this report is outlined as follows. First, background information is provided, including the history of fees under FLREA, history of the Interagency Pass, a summary of the University of Wyoming's 2006 pricing analysis, as well as a summary of recent reports on NPS recreation revenues. Next, an analysis of agency-level revenue, visitation, and entrance fee data is provided. An update to the University of Wyoming's 2006 pricing analysis is then presented, followed by recommendations for future study.

# Background

Federal recreation sites in the United States annually host hundreds of millions of visitors, including for 2015:

- 370 million visits to Army Corps of Engineers areas;[1]
- 307 million visits to National Park Service sites;[2]
- 188 million estimated visits to National Forest System sites;[3]
- 62 million estimated visits to Bureau of Land Management sites;[4]
- 48 million estimated visits to National Wildlife Refuges;[5] and
- 28 million estimated visits to Reclamation sites.[6]

Recreation facilities and opportunities at many of these sites are funded in part by visitors, through revenue collected under the Federal Lands Recreation Enhancement Act (FLREA). FLREA revenue, in the form of on-site fees and pass sales, is an important funding source for federal lands management, along with Congressional appropriations, donations, rents, commercial use fees, etc.

## History of Fees under FLREA

The National Recreation Fee Demonstration Program was created in 1996 as a three-year pilot program. This was followed by FLREA in 2004. Under FLREA federal land management agencies are authorized to collect fees from visitors, and to use those fees to develop and maintain public recreation sites. Participating agencies include the Department of the Interior's (DOI's) Bureau of Land Management (BLM), Bureau of Reclamation (Reclamation), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS); and the U.S. Department of Agriculture's (USDA's) Forest Service (USFS). The U.S. Army Corps of Engineers (USACE) was authorized to join the FLREA pass program in the 2014 Water Resources Reform and Development Act.[7]

[1] Annual average, from http://www.usace.army.mil/Missions/Civil-Works/Recreation/
[2] NPS Annual Visitation Summary Report for 2015 https://irma.nps.gov/Stats/SSRSReports/National%20Reports/Annual%20Visitation%20Summary%20Report%20(1979%20-%20Last%20Calendar%20Year)
[3] https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf
[4] BLM Public Land Statistics, FY 2015, Table 4-1. https://www.blm.gov/public_land_statistics/pls15/pls2015.pdf
[5] DOI data.
[6] DOI data
[7] Since the enactment of FLREA, interagency passes have been accepted at certain sites managed by the U.S. Army Corps of Engineers (USACE) and Tennessee Valley Authority.

FLREA authorizes the agencies to charge several types of fees:

- NPS and FWS charge *entrance fees* at sites like National Parks and Wildlife Refuges;
- BLM, USFS, and Reclamation charge *standard amenity recreation fees* at sites like picnic areas and interpretive sites;
- Agencies collect *expanded amenity recreation fees* for enhanced services such as a cabin rental, campgrounds, and boat launch facilities; and
- *Special Recreation Permits* for activities such as off-highway vehicle use, guiding, and events.

In deciding whether to establish or change fees at federally managed sites, the agencies engage with the public and stakeholders to ensure that the different perspectives are considered and that the fees are appropriate. Fees are currently charged at about 45% of NPS sites, 32% of USFS sites, 7% of FWS refuges, for 1% of BLM acreage, and a single Reclamation site. FLREA fee revenue has increased steadily from $196 million in Fiscal Year (FY) 2005 to $278 million in FY 2014 (DOI and USDA, 2015).

## NPS Entrance Fees

McKinsey & Co (2001) completed a study of NPS entrance fees finding that prices were not standardized across the nation. The authors recommended developing a national model to determine prices. In 2006, NPS implemented a model updating prices for entrance fees (per-person, per-vehicle, and per-motorcycle) and single-park annual passes. NPS sites were divided into four groups, based on type of site and visitation levels:

- Group 4 includes the nine most-visited parks (Bryce, Glacier, Grand Canyon, Grand Teton, Rocky Mountain, Sequoia-Kings, Yellowstone, Yosemite, Zion);
- Group 3 includes all other National Parks;
- Group 2 includes the more visited non-Park unit-types (e.g., Seashores, Monuments);
- Group 1 includes the less visited non-Park unit-types (e.g. National Battlefields, Parkways)

The 2006 model was initially implemented at 34 NPS units. In 2008 the National economy entered a recession, and NPS implemented a moratorium on increasing fees. In 2014, NPS lifted the moratorium and started applying fee increases using the updated pricing structure shown in Table 1. Proposed fee changes at an NPS site are subject to public review and comment through the “civic engagement” process. Proposed fees are reviewed by the Executive Committee and must be approved by the NPS National Leadership Council (NLC).

**Table 1. National Park Service Target Entrance Fees Based on Pricing Model (2014 Update)**

| Group | Site Types | Single-Park Annual Pass | Per Vehicle | Per Person | Motor-cycle |
|---|---|---|---|---|---|
| 1 | National Historic Sites, National Military Parks, National Battlefield Parks, National Memorials/Shrines, National Preserves, and Parkways | $30 | $15 | $7 | $10 |
| 2 | National Seashores, National Recreation Areas, National Monuments, National Lakeshores, and National Historic Parks | $40 | $20 | $10 | $15 |
| 3 | National Parks | $50 | $25 | $12 | $20 |
| 4 | National Parks | $60 | $30 | $15 | $25 |
| | Increase over 2006 Fees | $10 | $5 | $2,$3 | $5 |
| | Equivalent annual % increase | 2%-5% | 2%-5% | 2%-5% | 3%-9% |

Sources: DOI and USDA (2015); GAO (2015)

## History of the Interagency Pass

Prior to FLREA, various federal recreation sites accepted a variety of passes, including the Golden Eagle Passport, Golden Age Passport, Golden Access Passports, and the National Parks Pass. FLREA authorized a new interagency pass family called the "America the Beautiful - National Parks and Federal Recreational Lands Passes." Passes are sold at participating recreation sites, over the phone or online at websites like store.usgs.gov (so-called *central sales*), at third-party vendors (e.g., outdoors outfitters), and at certain agency offices. The agencies currently offer a variety of interagency passes accepted at FLREA sites around the country:

- An $80 Annual Pass;
- A $10 lifetime Senior Pass for those 62 and older;[8]
- A free Every Kid in a Park Pass for 4th graders;
- A free Access Pass for those with permanent disabilities;
- A free Annual Military Pass for members of the military and their families; and
- A free Volunteer Pass for those who volunteer 250 hours on public lands.

The agencies also have occasional fee-free days for the general public.

[8] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

FLREA requires the agencies to report to Congress every three years on implementation of the recreation fee program. The 2015 Triennial Report shows that pass sales have continued to increase, up to nearly one million passes annually. As shown in Table 2, for FY 2012 through FY 2014 over 80 percent of sales were made at NPS sites, with a further 8 or 9 percent of the total sold at USFS sites, and the remaining 10 or 11 percent sold at sites managed by other agencies. Of the total passes sold, about two-thirds are for the $10 Senior Pass, and one-third are for the $80 Annual Pass.

**Table 2. Proportion of Interagency Passes Sold, by Agency and Pass Type**

| | FY 2012 | | FY 2013 | | FY 2014 | |
|---|---|---|---|---|---|---|
| NPS pass sales | 763,124 | 81% | 792,062 | 82% | 798,683 | 80% |
| USFS pass sales | 84,093 | 9% | 80,298 | 8% | 81,007 | 8% |
| Other Agency pass sales | 92,158 | 10% | 98,873 | 10% | 113,341 | 11% |
| Pass Types (All Agencies) | | | | | | |
| Annual Passes | 314,835 | 34% | 329,530 | 34% | 356,016 | 36% |
| Senior Passes | 624,540 | 66% | 641,703 | 66% | 637,015 | 64% |
| Total Passes | 939,375 | 100% | 971,233 | 100% | 993,031 | 100% |

Source: DOI and USDA (2015)

There was a dramatic increase in pass sales in FY 2015, leading up to the 2016 NPS Centennial. In FY 2015, NPS sites saw a 33 percent increase in the level of Annual Passes sold, compared to FY 2014. USFS sites saw a similar increase in Senior Passes sold over the same period (though only a 4 percent increase for Annual Passes), and FWS reported a 25% increase in all Interagency Passes sold. Central and third party sales saw an increase of over 45 percent (though these sources typically make up about 2 percent of pass sales).[9]

Pass-holders gain free entry to many recreational sites managed by federal agencies, however there is no centralized tracking system available to determine where and when the passes are used. In 2016 NPS published “The National Parks and Federal Recreational Lands Pass Survey,” reporting the results of a survey of pass use among pass-holders who purchased a pass through central sales via the USGS website

[9] Data from DOI and USDA, in personal communications.

(rather than in person, at a recreation site). The repeat contact mail survey had a final response rate of 43.5%, with 772 completed surveys returned.

The survey asked respondents to recall the last five times they had used their pass to access a recreation site.[10] Overall, approximately 85% of pass use was reported to be at NPS sites, and about 8% at USFS sites. Reclamation, BLM, and USFWS sites saw 2% or less of reported pass uses (Bioeconomics, 2016).

## Summary of the University of Wyoming's 2006 Pricing Analysis

In 2005, the U.S. Department of Agriculture and the Department of the Interior issued a request for proposals to evaluate possible prices for the new Interagency Annual Pass. A project proposal submitted by the University of Wyoming, through its Wyoming Survey and Analysis Center, was selected to provide the requested assistance. The project consisted of five main tasks:

1. The production of a roadmap detailing the steps that would be taken to complete the remaining tasks;
2. A benchmarking study used to compare existing federal recreation passes with state and Parks Canada passes;
3. An examination of theoretical and methodological issues in the economics of non-market valuation;
4. Focus groups; and
5. A national telephone survey.

The overall goal of the project was to provide information from multiple sources that could assist policymakers in determining a price for the new Interagency Annual Pass. The national telephone survey in particular provided comprehensive information on the number of households that would be expected to purchase the pass at various prices. This information was then used to forecast revenues from the sale of the pass, as well as gate revenues, across all agencies at various pass prices. In addition, the request for proposals stipulated that the price of the pass "should at least allow the government to break even in the sense that, on average, the sale of the pass does not result in a loss of revenue relative to the revenue that would be received absent the ability to purchase an annual pass." To address this, the researchers also evaluated foregone revenue (total revenues in the absence of the pass program minus total revenues with

[10] The survey also asked about 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

the pass program) at various pass prices. They determined that the price of the pass would need to be set at $125 or above to come close to revenue neutrality, assuming gate entrance fees remained at their current level. At the time of the study, $125 was equal to the cost of an annual pass for California's state parks, and was less than the price of an annual pass for Parks Canada. A novel addition to their analysis was the use of Golden Eagle and National Parks Pass sales data to calibrate hypothetical willingness-to-pay values with real choices. Now that the Interagency Annual Pass has been available for the last ten years, this calibration can be updated using current data on the number of passes sold at a price of $80. This will provide some indication of how pass sales and associated revenues might be expected to change at different pass prices. The details of this analysis are presented later in this report.

### Recent Reports on NPS Recreation Revenues

This section focuses on the National Park Service, though the conclusions are generally applicable across all FLREA agencies. GAO (2015) found that total funding for the National Park Service (NPS) has not kept pace with inflation in recent years, making FLREA revenue an increasingly important part of total NPS funding. Recognizing this increasing importance, GAO recommended that NPS periodically review entrance fees for potential updates. GAO also recommended amendments to FLREA so that the federal agencies can adjust pass prices, in particular the $10 lifetime Senior Pass.

OIG (2015) examined opportunities for the National Park Service (NPS) to increase its recreation program revenues, focusing on the three largest sources of recreation revenues: park-unit entrance fees, interagency passes, and commercial bus tour fees. OIG recommended that NPS establish intervals for periodic reviews to ensure that prices for these three revenue sources remain up to date. In particular, OIG recommended updating the price of the $80 Annual Pass.[11]

## Agency-level Study

This section summarizes data on FLREA revenues collected by the agencies in recent years.

### National Park Service (NPS)

NPS service-wide revenues from the sale of single-park annual passes, the Interagency Annual Pass, and daily admission/entrance fees from 2007 to 2016 are shown in Figure 1. In general, revenues from all

[11] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

sources have seen large increases since 2014, both in nominal dollars and after adjustment for inflation. Revenue from the sale of single-park annual passes has increased by about 25% since 2014, revenue from the sale of the Interagency Annual Pass has increased by nearly 70%, and revenue from entrance fees has increased by about 45%. This boost in revenues is partly due to increased visitation to NPS sites, which could be related to the 2016 NPS Centennial and efforts such as the 'Find Your Park' campaign. Although finalized 2016 visitation data are not yet available, many parks are already reporting record-breaking visitation.

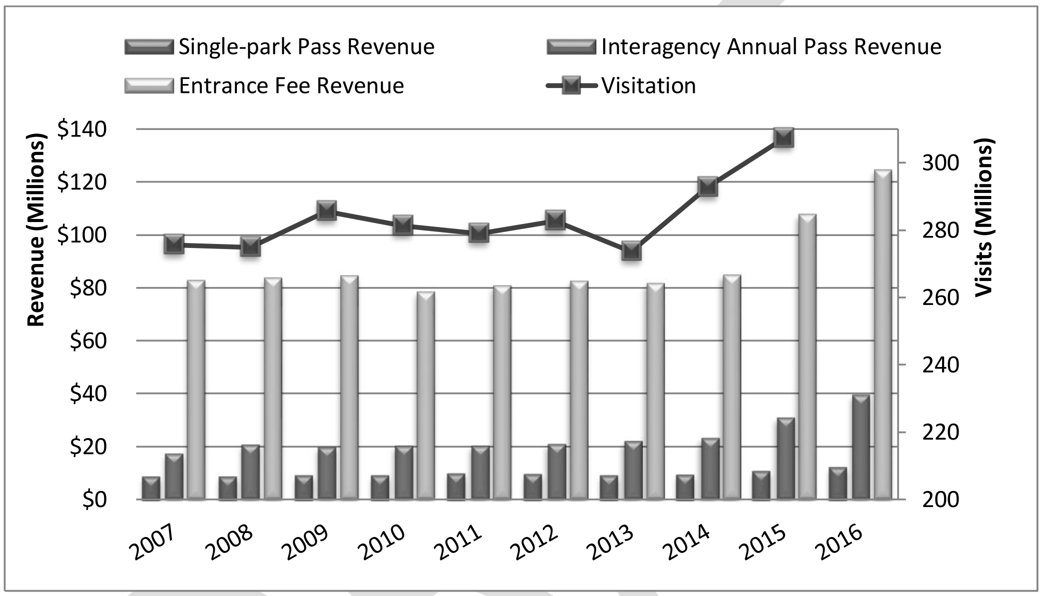


Figure 1. NPS Service-wide Revenues and Visitation, 2007-2016

## U.S. Fish and Wildlife Service (FWS)

Data for FY 2013 through FY 2015 show that FWS visitation and fee revenues followed a similar pattern to that of NPS, though with a less dramatic increase in FY 2015 (Figure 2). However, in FY 2016 FWS saw a drop in fee revenues, as opposed to NPS' continued increase.

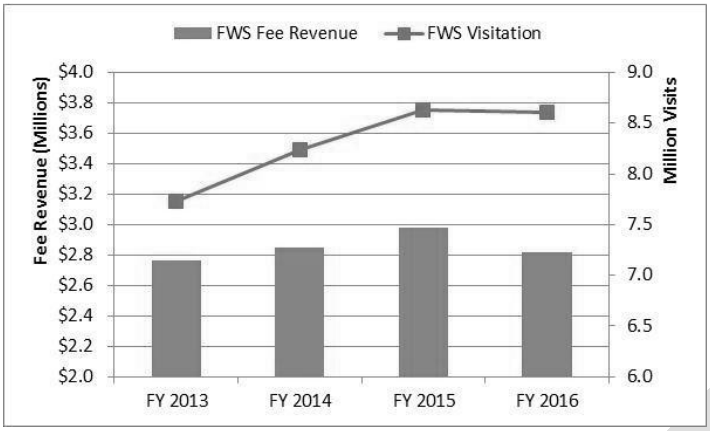


Figure 2. FWS Fee Revenue and Visitation, FY13-FY16 (34 Sites)

## Bureau of Land Management (BLM)

As shown in Figure 3 BLM has seen about a 7 percent increase in visitation over the past four years, from an estimated 58,070 visitors in FY 2013 to 62,399 in FY 2016. Meanwhile, standard and amenity fee revenues have increased by nearly 20 percent.[12]

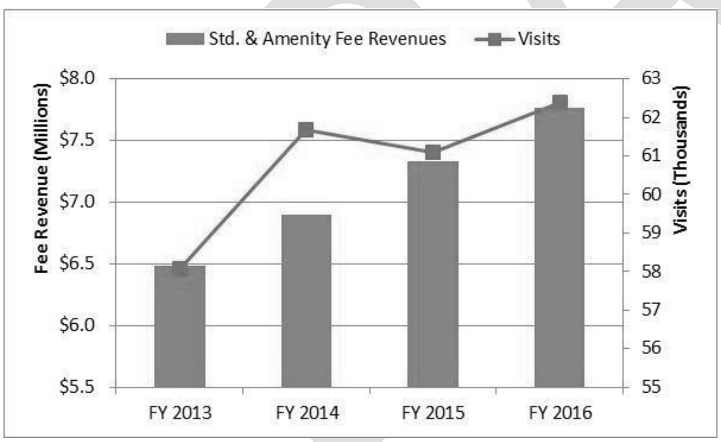


Figure 3. BLM Fee Revenue and Visitation, FY 2013 – FY 2016

Figure 4 shows sales of the Interagency Pass at BLM sites. The $80 Annual Pass saw a steady increase from 3,858 passes in FY 2012 to 7,506 in FY 2015. This was followed by a fall to 5,511 passes sold in FY 2016. This may be an effect of the NPS Centennial in 2016, with more BLM site users also visiting

[12] Source: BLM Public Land Statistics (PLS). Other forms of fee revenue reported by BLM in PLS include expanded amenity fee permits; special area permits; commercial competitive, group, and event permits; and leases.

NPS sites, and purchasing their passes at those sites. In contrast, sales of the senior pass have continued to increase, from 16,186 in FY 2012 to 21,497 in FY 2015, and 22,722 in FY 2016.

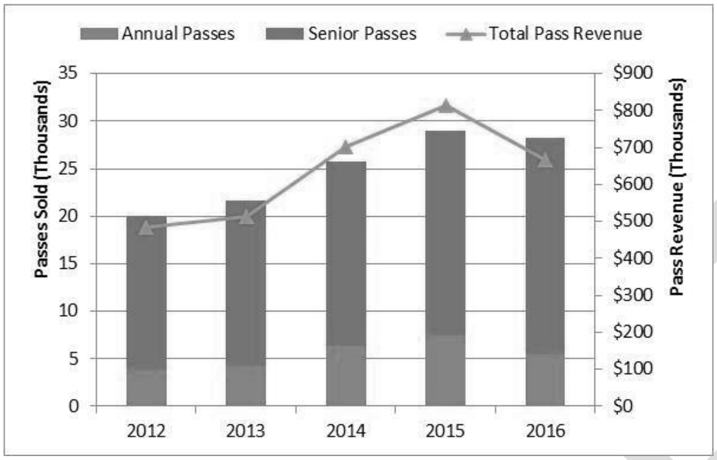


Figure 4. Annual and Senior IA Passes Sold at BLM Sites (2012-2016)

## U.S. Forest Service (USFS)

USFS makes a relatively large proportion of their fee revenue from sales of passes for particular USFS sites, such as multi-day, weekly, season, annual and "grand annual" passes; and passes for a household or vehicle; and "joint" passes such as the $50 joint pass covering both Arapaho National Recreation Area and Rocky Mountain National Park. Table 3 summarizes USFS fees and passes for FY 2016.

Table 3. USFS Fees Summary (FY 2016)

| Revenue Source | Types of Fee/Pass | Price |
|---|---|---|
| Day Use Fees | Per-person | $2-$12 |
| | per bicycle | $3 |
| | bus | $10 |
| Passes | 3-day | $10 |
| | 7-day | $15-$20 |
| | week | $10-$15 |
| | season | $40 |
| | seasonal | $25 |
| | season/off season | $30/$20 |
| | annual | $15-$80 |
| | grand annual | $40 |
| | vehicle | $18-$20 |
| | household | $25-$45 |

As shown in Figure 5, for FY 2016, about three-quarters of fee revenue came from such single-site passes, with the remaining quarter coming from amenity fees deposited by visitors in on-site fee-deposit vaults, or "fee tubes."

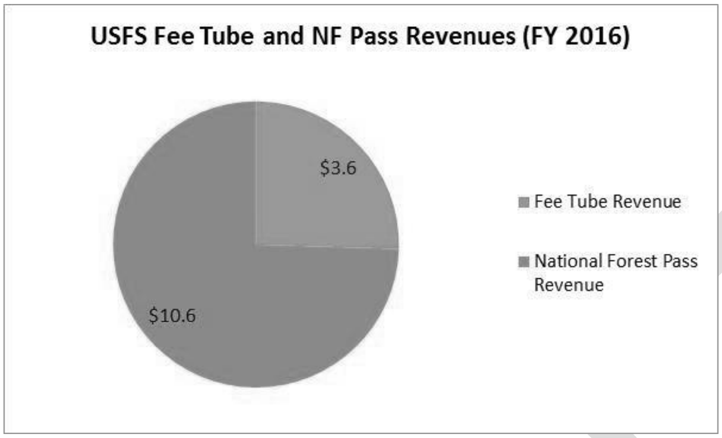


**Figure 5. USFS Revenues (FY 2016)**

## Fee Prices Charged at Sites

In addition to trends in total revenues and visitation, prices represent another important piece of information. There is some variety in how entrance fees and amenity fees are set by the different agencies. For example, as shown in Table 3, USFS fees vary by site, length of time, and season. FWS fees charged at 34 refuges include single-site annual passes ranging from $10 to $30, and daily per-vehicle fees ranging from $2 to $8.[13] The US Army Corps of Engineers (USACE) joined the FLREA agencies on January 1, 2016, and at this time they raised their per-vehicle fee from $3 to $5, and the price of their USACE annual pass from $30 to $40.[14]

We considered the relationship between visitation and entrance fees. For USFS we considered daily fees for 49 National Forests for which we had visitation figures. In FY 2016, there was relatively low correlation (a Pearson's correlation coefficient of 0.15) between daily fees and visitation. For FWS data from FY 2013 to FY 2016, there is a positive correlation between visitation and fee levels: about 0.46 for daily entrance fees, and 0.55 for annual fees, over the four-year period, indicating that more popular refuges tend to have higher fees. This correlation seems to be growing stronger over time; in the absence of price changes this indicates that popular refuges are becoming more popular.

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[13] Kaua'i NWR Complex charges $5 per person, rather than a per-vehicle fee.
[14] Future research will examine how these price changes impacted visitation at USACE sites.

We were able to obtain detailed data on access fees for NPS sites. Although the price of the Interagency Annual Pass has remained at $80, park entrance fees and the price of single-park annual passes have changed over time, especially after the moratorium on fee increases was lifted in 2014. For those parks that charge an entrance fee, Figure 6 shows the average per-person and per-vehicle entrance fee charged from 2007 to 2016, as well as the average price of single-park annual pass for those parks that offer such passes.

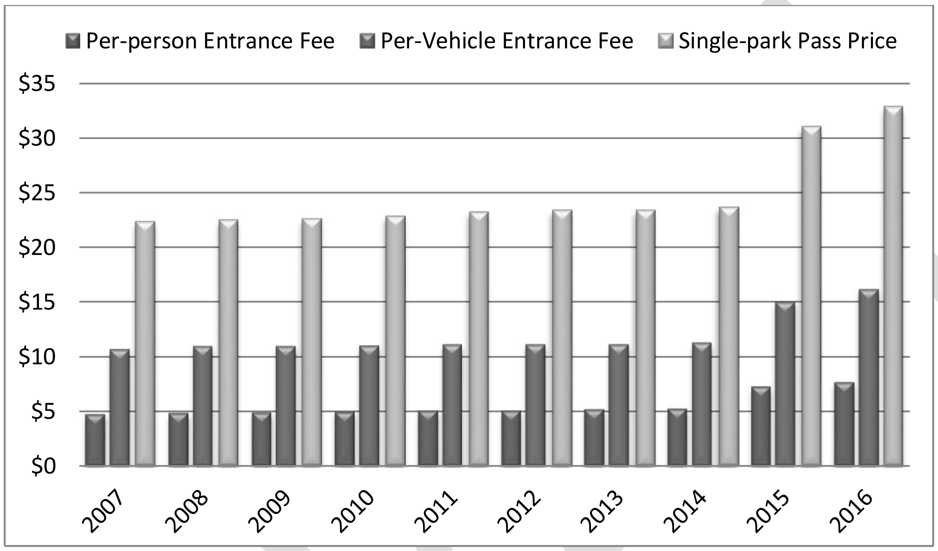


**Figure 6. Average Per-Person Entrance Fee, Per-Vehicle Entrance Fee, and Individual Single-Park Pass Price (NPS Sites, 2007-2016)**

Over that time period, per-person entrance fees increased by about 60% on average (39% when adjusted for inflation), and per-vehicle entrance fees have increased by more than 50% (31% when adjusted for inflation). Just since 2014, per-person and per-vehicle entrance fees have increased by more than 40% on average. The average price of a single-park annual pass has increased by about 45% since 2007 (25% when adjusted for inflation) and by more than 35% since 2014. Again, this large increase since 2014 is a result of NPS lifting the moratorium that year and applying fee increases using the updated pricing structure shown in Table 1. As shown in Table 4, the equivalent annual percentage increase in entrance fees and single-park pass prices from 2007 to 2016 would be about 3 to 5 percent. If the Interagency Annual Pass were adjusted for inflation, the pass that cost $80 in 2007 would cost about $93 in 2016.

**Table 4. NPS Average Entrance Fees**

| | Per-Person Entrance Fee | Per-Vehicle Entrance Fee | Single-Park Annual Pass |
|---|---|---|---|
| Average in 2007 | $4.74 | $10.63 | $22.37 |
| Average in 2016 | $7.65 | $16.16 | $32.82 |
| Percentage increase from 2007 to 2016 | 61% | 52% | 47% |
| Percentage increase from 2007 to 2016, adjusted for inflation | 39% | 31% | 26% |
| Equivalent annual % increase | 4%-5% | 3%-5% | 3%-4% |

There are two important takeaways from this review of recreation fees and revenues over time:

- At least for NPS sites, visitation appears to be relatively unresponsive to price increases associated with site access. There have been large increases in the average price of entrance fees and single-park passes, and revenues across all sources have continued to increase, both in nominal and real dollars. This is consistent with previous findings that entrance fees alone are not a barrier to more frequent visitation of NPS units (Ostergren et al., 2005; Factor, 2007). Of course, entrance and other site access fees typically represent only a small portion of the total trip cost that must be considered when making the decision to visit a recreation site. Further study of the relationship between visitation and access fees for other federal lands could be informative, for example, evaluating visitation data for USACE before and after this agency joined the Interagency Annual Pass program.
- The University of Wyoming's 2006 pricing analysis for the Interagency Annual Pass (discussed in greater detail below) highlighted the fact that whatever base price was ultimately chosen for the pass could be adjusted in advance to account for future increases in gate fees. They explain that while the pass might realistically see cost of living adjustments every three years or so, gate fees could increase more often than that. Assuming that average gate fees increase by 10% over a three-year period, the Interagency Annual Pass would need to include a 10% premium at the outset to ensure that it satisfies revenue neutrality. In reality, while entrance fees across the National Park System (and possibly other federal lands) have increased significantly over the last few years, the price of the Interagency Annual Pass has remained at $80.

## Updating the University of Wyoming's 2006 Pricing Analysis

In 2006, researchers at the University of Wyoming completed an analysis to assist with pricing of the new Interagency Annual Pass (hereafter referred to as Aadland and Shogren, 2006). The basis of the analysis was a nationwide telephone survey administered to two independent strata: a nationally representative sample of U.S. households obtained through random digit dialing (RDD sample) and a random sample of households known to the National Park Foundation to have purchased a National Parks Pass between April 2004 and March 2005, which included mainly those households that purchased the pass online (NPF sample). The analysis is based on the assumption that an individual household will choose to buy the new Interagency Annual Pass if the benefits of doing so outweigh the costs. It is initially assumed that the primary motivation for purchasing the pass is based solely on its economic value; that is, people will purchase the pass if it reduces their expected costs associated with visitation to federal recreation sites. The policymaker's decision is to choose the price of the pass to maintain revenue neutrality; i.e., total revenues across all agencies participating in the pass program will not be less than total revenues in the absence of the pass program.

To determine how much respondents would be willing to pay for the new Interagency Annual Pass, the study used a nonmarket valuation method known as Contingent Valuation (CV). After a short description of the new pass, households that had visited federal recreation lands in the last two years were presented with a dichotomous choice CV question in which they were asked if they would be willing to purchase the pass at a randomly selected price, ranging from $25 to $165. After responding 'yes' or 'no,' they were asked a follow-up CV question to more precisely determine their actual willingness-to-pay for the pass. If the respondent answered 'no' to the first price, they were presented with a lower price and asked if they would be willing to purchase the pass. If the respondent answered 'yes' to the first price, they were presented with a higher price and asked if they would be willing to purchase the pass. Using the results from this series of questions and scaling to the relevant population of potential pass purchasers, Aadland and Shogren (2006) were able to project the number of households that would be expected to purchase the pass at various prices. To do so, they rely on two different estimates:

1. Unconditional estimates – these estimates do not rely on any econometric model, but rather, are derived directly from households' responses to the two CV questions. For example, if a respondent said 'yes' to a pass price of $65, but 'no' to a pass price of $85, their true willingness-to-pay is assumed to be the midpoint of this interval, or $75. If a respondent said 'yes' to a pass price of $65 and 'yes' to a pass price of $85, they are assigned a willingness-to-pay value of the

high price plus $10, or $95 in this example. Finally, if a respondent said ‘no’ to a pass price of $65 and ‘no’ to a pass price of $45, they are assigned a willingness-to-pay value equal to half of the lower price, or $22.50.

2. Conditional estimates – these estimates are derived from an econometric model, specifically, an interval regression model. There is a probability associated with each household’s possible series of responses to the two CV questions – yes/yes, no/no, yes/no, and no/yes. These probabilities are used to create a log likelihood function, and the regression coefficients are then chosen to maximize this function. Predicted willingness-to-pay estimates for every household in the sample can then be calculated based on these results.

As with any application of the Contingent Valuation Method, survey respondents are asked to make a hypothetical purchasing decision. However, since they are not actually required to pay what they say they will, respondents may overstate their willingness-to-pay. To address this possible hypothetical bias, Aadland and Shogren (2006) used outside information on real market transactions to ‘calibrate’ their projected demand estimates. Specifically, revenues from the sale of the National Parks Pass and the Golden Eagle Pass were used to scale the projected Interagency Annual Pass revenues (and number of pass-holders, which is just total revenue divided by price) in an effort to better reflect the actual purchasing decisions of consumers. Now that we have ten years of sales data for the Interagency Annual Pass at a price of $80, we can use this information to update the external calibration for hypothetical bias and more accurately capture current demand for the pass. Across all agencies, sales of the Interagency Annual Pass from 2009 to 2014 were as follows:

**Table 5. Interagency Annual Passes Sold by Year and by Agency**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| BLM | 2,434 | 2,765 | 3,874 | 3,858 | 4,267 | 6,348 |
| FWS | 1,667 | 1,771 | 1,922 | 1,819 | 2,014 | 1,926 |
| NPS | 243,281 | 259,580 | 251,779 | 262,678 | 276,824 | 290,035 |
| BOR | 29 | 48 | 56 | 62 | 161 | 20 |
| USFS | 18,287 | 18,329 | 18,469 | 18,537 | 17,557 | 20,871 |
| Central Sales | 21,300 | 22,178 | 18,942 | 16,948 | 18,363 | 23,360 |
| Third Party | 3,144 | 6,387 | 7,842 | 10,933 | 10,344 | 13,456 |
| Total | 290,142 | 311,058 | 302,884 | 314,835 | 329,530 | 356,016 |

Based on the last three years that data are available, total Annual Pass sales have averaged around 333,460 per year at a pass price of $80. This price/quantity point is used to calibrate the unconditional and conditional demand estimates from Aadland and Shogren (2006). For instance, if their estimates predicted that there would be 450,000 passes demanded at a price of $80, but we know there were only 333,460 passes sold at a price of $80, then we divide the number of predicted passes demanded at each price by a factor of 1.35 (450,000/333,460). This is essentially shifting the entire demand curve to more accurately project the number of passes that could be expected to be sold at various prices. We focus on the RDD sample only since the NPF sample accounts for a very small and specific group of pass purchasers from 2006. As noted by Aadland and Shogren (2006), if the two samples were combined and weighted to reflect their relative population sizes, the combined results would be virtually indistinguishable from an analysis of the RDD sample alone.

As with most goods bought and sold in the marketplace, as the price of the pass increases, the quantity of passes demanded will decrease, all else constant. The extent of this decrease depends on how responsive people are to price changes, a relationship known as the *price elasticity of demand*. For a particular good, this elasticity is calculated as the percentage change in quantity demanded divided by the percentage change in price. An elasticity less than one in absolute value shows that demand is inelastic – that is, people are relatively unresponsive to price changes, and the percent change in quantity demanded is less than the percent change in price. In this case, revenues (price times quantity sold) will increase as the price increases; additional revenues from people who continue to purchase the pass is greater than the loss in revenue from those who no longer purchase the pass. Conversely, an elasticity greater than one in absolute value shows that demand is elastic – that is, people are more responsive to price changes, and the percent change in quantity demanded is greater than the percent change in price. In this case, revenues will decrease as the price increases; additional revenues from people who continue to purchase the pass do not make up for the loss in revenue from those who no longer purchase the pass due to the higher price.

Using updated calibration factors based on current sales data, we estimate the projected number of pass-holders, price elasticity of demand, and pass revenue (in aggregate across all agencies) for both the unconditional and conditional estimates at various pass prices. These results are shown in Table 6. Based on the unconditional estimates, people are relatively unresponsive to small increases in the price of the pass from the current price of $80 up to about $95. Thus, we see an increase in pass revenue as the pass price increases from $80 up to $95. Beyond that, the estimates predict large decreases in the number of passes sold and therefore, a decrease in pass revenue. The conditional estimates tell a different story -

people are relatively responsive to price increases, resulting in a loss in pass revenue as the pass price increases beyond $80. It should be noted that Aadland and Shogren (2006) put more confidence in the unconditional estimates compared to the conditional estimates. This is due to the fact that the econometric model used to generate the conditional estimates tended to do a better job of predicting willingness-to-pay for households on the low end of the willingness-to-pay distribution than on the high end. Because of the poorer fit at the high end, the model tends to incorrectly predict that households will not purchase the pass at high prices (resulting in larger elasticities at high pass prices). Given the difference in the two estimates, we also estimated an econometric model based on households' responses to the first CV question only (ignoring responses to the follow-up question), as the literature has found some evidence of internal inconsistency between responses to the first and second CV questions (Bateman et al., 2001; Cameron and Quiggin, 1994). The results of this model fell between the unconditional and conditional estimates, but aligned more closely with the unconditional estimates. These results predict that demand is inelastic at price increases from $80 up to about $90 (with pass revenue of $26.6 million), but once the pass price hits around $95 and beyond, demand becomes elastic and pass revenues begin to drop.

**Table 6. Projected Number of Pass-holders, Price Elasticity of Demand, and Pass Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders |
| $60 | 561,233 | | 33.7 | 549,228 | | 33.0 |
| $65 | 403,684 | -3.37 | 26.2 | 509,998 | -0.86 | 33.1 |
| $70 | 399,840 | -0.12 | 28.0 | 451,152 | -1.50 | 31.6 |
| $75 | 391,843 | -0.28 | 29.4 | 353,075 | -3.04 | 26.5 |
| $80 | 333,460* | -2.23 | 26.7* | 333,460* | -0.83 | 26.7* |
| $85 | 320,559 | -0.62 | 27.2 | 274,614 | -2.82 | 23.3 |
| $90 | 310,986 | -0.51 | 28.0 | 235,384 | -2.43 | 21.2 |
| $95 | 308,664 | -0.13 | 29.3 | 215,768 | -1.50 | 20.5 |
| $100 | 279,888 | -1.77 | 28.0 | 196,153 | -1.73 | 19.6 |
| $105 | 273,065 | -0.49 | 28.7 | 176,538 | -2.00 | 18.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| $110 | 206,735 | -5.10 | 22.7 | 156,922 | -2.33 | 17.3 |
| $115 | 189,974 | -1.78 | 21.8 | 137,307 | -2.75 | 15.8 |
| $120 | 189,507 | -0.06 | 22.7 | 137,307 | 0.00 | 16.5 |

*actual

NB: Shading indicates inelastic portions of the demand curve (estimated elasticity of demand less than 1.0 in absolute value).

Next we calculate projected gate revenues at various Interagency Annual Pass prices, following the approach taken by Aadland and Shogren (2006). Each household has a particular willingness-to-pay for the pass, and the most they should be willing to pay for the pass is the amount they expect to spend at the gate for all sites they plan to visit that year. They will purchase the pass if their willingness-to-pay is greater than or equal to the price of the pass. If their willingness-to-pay is less than the price of the pass, they won't purchase the pass, but it is assumed that they will pay their exact willingness-to-pay in gate entrance fees at various recreation sites. For example, say the pass costs $80 but a household is only willing to pay $60 for it. Since their willingness-to-pay is less than the price of the pass, they will not purchase it, but may instead visit a park that charges a $20 entrance fee three times in one year, or alternatively, they may visit a site that charges a $10 entrance fee six times in one year, spending their exact $60 willingness-to-pay to access federal recreation sites. This approach assumes that households do not systematically over or underestimate the expected number of trips to federal recreation sites, and that the decision to purchase the pass is based solely on its economic value. Therefore, at a particular pass price, total gate revenue is calculated by summing willingness-to-pay for all households with willingness-to-pay less than the price of the pass, scaled to the relevant population. Table 7 shows projected pass revenue, gate revenue, and total revenue (pass revenue + gate revenue) at pass prices ranging from $60 to $120. These estimates are calibrated for hypothetical bias, and again, represent totals across all agencies participating in the pass program. The unconditional estimates show pass revenue increasing as the price of the pass increases from the current price of $80 up to about $95, and gate revenues and total revenues continue to increase as the price of the pass increases. The conditional estimates show pass revenue decreasing at prices beyond $80, but gate revenues and total revenues steadily increase as the price of the pass increases.

**Table 7. Projected Pass Revenue, Gate Revenue and Total Revenue (Pass+Gate) at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) |
| $60 | 33.7 | 181.1 | 214.7 | 33.0 | 213.8 | 246.8 |
| $65 | 26.2 | 191.5 | 217.8 | 33.1 | 216.3 | 249.5 |
| $70 | 28.0 | 191.8 | 219.8 | 31.6 | 220.2 | 251.8 |
| $75 | 29.4 | 192.4 | 221.8 | 26.5 | 227.2 | 253.7 |
| $80 | 26.7* | 194.2 | 220.8 | 26.7* | 228.8 | 255.4 |
| $85 | 27.2 | 195.0 | 222.3 | 23.3 | 233.6 | 256.9 |
| $90 | 28.0 | 195.9 | 223.9 | 21.2 | 236.9 | 258.1 |
| $95 | 29.3 | 197.7 | 227.0 | 20.5 | 238.7 | 259.2 |
| $100 | 28.0 | 199.4 | 227.4 | 19.6 | 240.6 | 260.2 |
| $105 | 28.7 | 199.9 | 228.5 | 18.5 | 242.6 | 261.1 |
| $110 | 22.7 | 208.2 | 230.9 | 17.3 | 244.7 | 262.0 |
| $115 | 21.8 | 209.0 | 230.9 | 15.8 | 246.8 | 262.6 |
| $120 | 22.7 | 209.0 | 231.8 | 16.5 | 246.8 | 263.3 |

*actual

Finally, we calculate foregone revenue, again following the approach taken by Aadland and Shogren (2006). Foregone revenue is simply total revenues in the absence of the pass program minus total revenues with the pass program. Setting the price of the pass in a way that doesn't sacrifice substantial revenues (in aggregate across all agencies) would require foregone revenue to approach zero. This would imply that the program is revenue neutral. Total revenues with the pass program are shown in Table 7. To estimate total revenues in the absence of the pass program, we simply sum willingness-to-pay for every household in the sample, and scale it to the relevant population. This assumes that, if a household does not have the option to purchase the Interagency Annual Pass, they will simply spend their exact willingness-to-pay for the pass on gate entrance fees at federal recreation sites. Estimates of foregone revenue at various pass prices, also calibrated for hypothetical bias, are shown in Table 8. Under both the

unconditional and conditional estimates, foregone revenue is predicted to continue to decrease as the price of the pass increases.

**Table 8. Projected Foregone Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | Conditional Estimates |
|---|---|---|
| Pass Price | Foregone Revenue (millions of dollars) | Foregone Revenue (millions of dollars) |
| $60 | 27.1 | 21.3 |
| $65 | 25.4 | 18.6 |
| $70 | 23.6 | 16.3 |
| $75 | 21.4 | 14.3 |
| $80 | 18.8 | 12.6 |
| $85 | 17.9 | 11.1 |
| $90 | 16.6 | 10.0 |
| $95 | 16.4 | 8.9 |
| $100 | 13.6 | 7.8 |
| $105 | 12.1 | 6.9 |
| $110 | 10.1 | 6.1 |
| $115 | 9.9 | 5.4 |
| $120 | 7.9 | 4.7 |

In summary, based on the analysis outlined in Aadland and Shogren (2006), which has been updated using recent sales data, increasing the price of the Interagency Annual Pass from the current price of $80 is expected to result in increased total revenues (and thus decreased foregone revenues) across all agencies participating in the pass program. Further, based on the unconditional estimates, small increases in the price of the Interagency Annual Pass are not expected to greatly reduce demand, meaning revenue from the sale of the pass may also increase if it's sold at a slightly higher price.

This analysis has assumed that people's motivation for buying the pass is based on economic considerations alone - that is, they will buy the pass if it reduces their expected costs associated with visitation to federal recreation sites. This is a realistic assumption given that the majority of survey

respondents agreed that "the price of the pass compared to the cost of entrance fees" is an important reason to purchase the pass. This was also the primary motivation reported by the Biometrics (2016) survey of central-sales pass purchasers. However, if people are motivated to purchase the pass for other reasons, such as the convenience of not having to make separate entrance fee payments at each site or because they view the pass as a means to maintain and enhance federal lands and facilities, then foregone revenues would be lower at every price point.

Lastly, it is important to note that although the results from Aadland and Shogren (2006) have been updated using current sales data, they are still based on responses to a survey that was conducted more than a decade ago. People now have ten years of experience using the Interagency Annual Pass. A new study would be required to determine whether this experience, or any other factors, have impacted people's motivations for buying the pass or caused potential pass purchasers to be more or less responsive to price changes than indicated by the results presented here.

## Recommendations for Future Study

There are various reasons that program managers may want to consider conducting a new study of the Interagency Annual Pass. The most recent economic analysis used to assist in pricing of the pass was completed more than ten years ago, and many changes have occurred since then. The Annual Pass is no longer a hypothetical good, and the public now has a decade of experience and familiarity with it. The pass itself has evolved over time. For instance, it provides access to additional federal recreation sites that have been designated since 2006, and recreation sites managed by the U.S. Army Corps of Engineers are now included in the program. In addition, population, per capita income, and prices have increased in the last ten years, and many federal recreation sites now charge higher entrance fees. Any of these factors have the potential to affect people's motivations for purchasing the pass and the amount that they are willing to pay for it.

It may also be worth developing data on prices of alternatives, such as entrance fees and pass prices for State parks, or Parks Canada. For example, California's State parks pass is now priced at $195. A total of 36 States appear to offer an annual pass, and a further 7 States have no charge for visiting State parks.[15] It may also be worth collecting data on entrance fees at other types of substitute activities (e.g., amusement parks). A broader study could look at how entrance fees figure into travel planning; this would inform estimates of sensitivity to price changes. An area offering the potential for general improvements for

[15] http://usparks.about.com/od/usstateparks/tp/State-Park-Passes.htm

managing recreation lands is improving visitation estimates. For example, NPS Visitor Use Statistics and the USFS National Visitor Use Model offer rigorous approaches that could be adopted at other agencies.

For a better understanding of the mechanics of revenue neutrality, it could be useful to study the effect of recreation price changes on site conditions, both directly (via maintenance budgets) and indirectly (via visitation levels). A review of the interaction between prices, visitation, and site conditions (e.g., resource conditions, crowding, required maintenance, etc.) at federal and State sites could prove informative as FLREA agencies review their pricing policies. Walls (2016) suggests that seasonal prices are an effective way to address crowding and to deal with maintenance requirements that increase with visitation.

If it is determined that a comprehensive study of the Interagency Annual Pass is warranted, a new pricing analysis could provide updated and more accurate information on: 1. The expected number of Interagency Passes sold and associated revenues at various prices (i.e., the demand curve); 2. The sensitivity of passes demanded to price changes (i.e., the price elasticity of demand); 3. The price of the pass required to maintain revenue neutrality, if that is determined to be a goal. A survey-based economic valuation method similar to the one outlined in Aadland and Shogren (2006) would most likely be used to obtain this information. It would be worthwhile to survey a random sample of U.S. households, as well as households known to have purchased the Interagency Annual Pass.

In addition to the economic analysis, a detailed evaluation of people's motivations for buying the pass could be undertaken to complement the findings in the survey of centrally sold pass purchasers (Bioeconomics, 2016).[16] These motivations can affect total revenues as well as foregone revenues at various pass prices, as shown in Aadland and Shogren (2006). Additional survey questions similar to those used in the central-sales survey could be included to determine other information that would be useful to the interagency pass program, such as people's satisfaction with the current Interagency Pass and the effectiveness of marketing techniques. A survey of the American public such as this could also potentially provide information about other high-priority issues for the agencies. Detailed discussions with program managers would be necessary to determine the specific goals of such a study. A comprehensive study would most likely require survey development, focus groups, and OMB approval, and would take approximately 18-24 months to complete. Additional funding would be required for a contractor to assist DOI/NPS with this effort.

[16] The Bioeconomics survey covered a variety of topics, including 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-02-06T08:34:15-05:00
**Importance:** Normal
**Subject:** EKiP Redemption Report
**Received:** 2017-02-06T08:34:46-05:00
EKIP Redemption Data 9-1-2016 - 1-31-2017.xlsx

Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong. Sites have reported issuing 70,436 plastic passes, nearly as many as were issued through May last year! Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

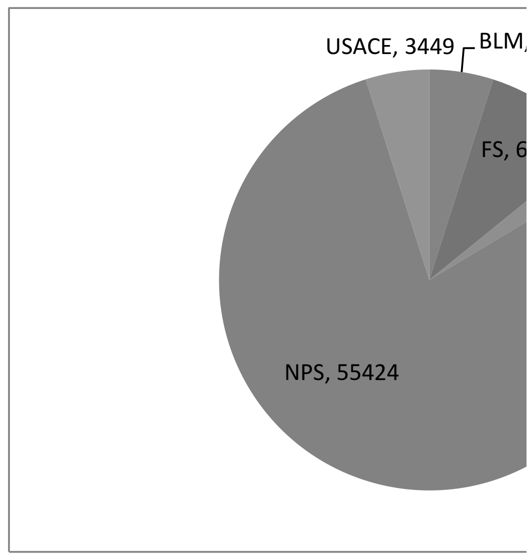
# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 1/31/2017**

**FOR INTERNAL USE ONLY**

| | |
|---|---|
| **Grand Total** | **70,436** |
| **BLM** | **3,464** |
| California BLM Office | 717 |
| Red Rock Canyon National Conservation Area BLM | 553 |
| Eagle Lake BLM Field Office | 351 |
| National Historic Trails Interpretive Center | 256 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| Red Rock Canyon National Conservation Area - BLM | 203 |
| Klamath Falls Resource Area | 189 |
| BLM Eastern States Office | 163 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Gunnison Gorge National Conservation Area | 109 |
| Redding BLM Field Office | 83 |
| Nevada BLM Office | 83 |
| Coos Bay BLM District Office | 69 |
| Rio Puerco BLM Field Office | 59 |
| BLM Medford Office | 54 |
| Colorado BLM Office | 46 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Miles City BLM Office | 13 |
| Royal Gorge BLM Field Office | 4 |
| Utah BLM Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Spokane BLM Office | 2 |
| Arizona BLM State Office | 2 |
| Wyoming BLM Office | 1 |
| Eugene District BLM Office | 1 |
| Rock Springs Field Office - BLM | 1 |
| **FS** | **6,517** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Stanislaus NF - Mi-Wok District | 500 |
| Lincoln NF - Sacramento District | 397 |
| US Forest Service Region 9 | 331 |
| Umpqua NF - Main Office | 330 |
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Fremont-Winema NF - Main Office | 240 |

**4.9%**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NPS, 55424

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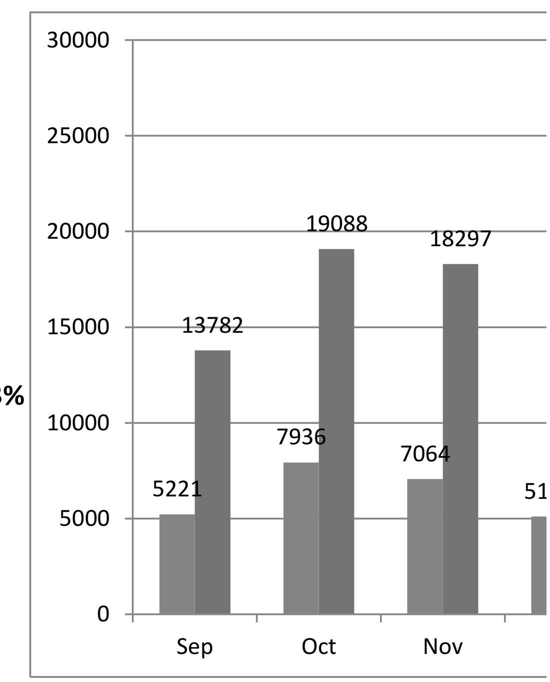
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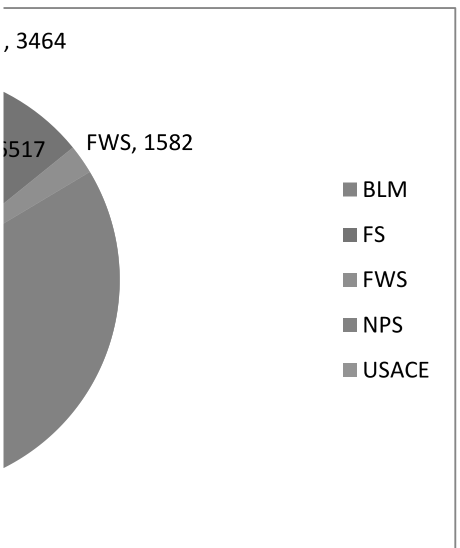


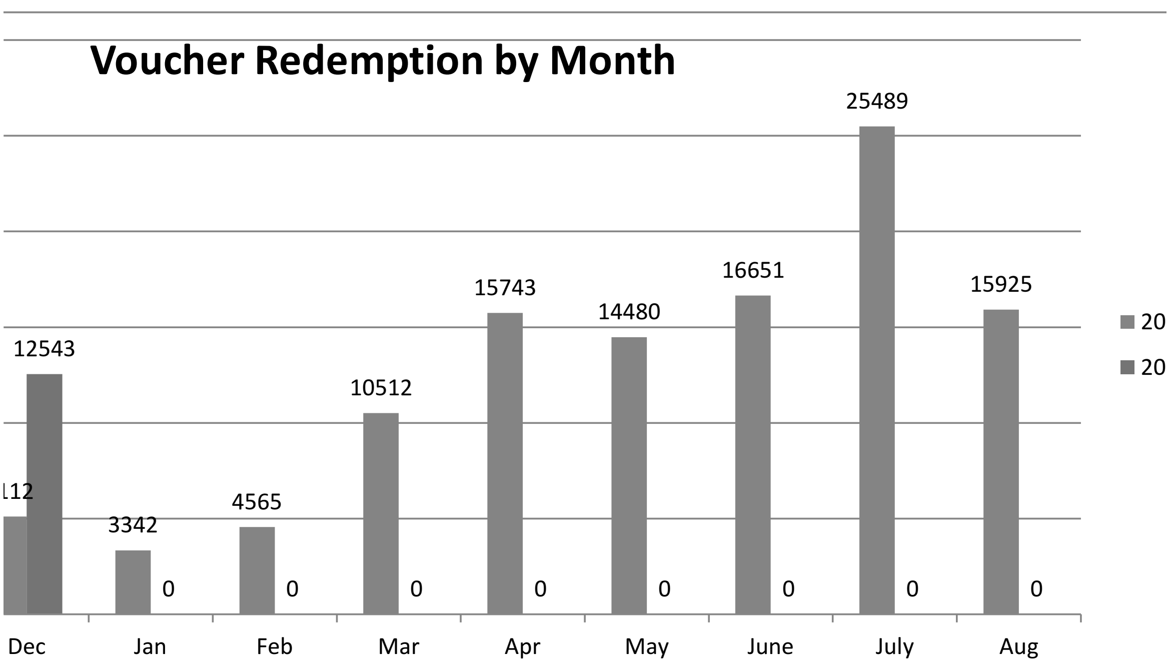

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| US Forest Service Regional Office | 238 |
| Rogue River - Siskiyou NF - Main Office | 192 |
| Land Between the Lakes | 190 |
| Chugach National Forest | 184 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 133 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Ocala NF - Lake George District | 110 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Caribou-Targhee NF - Dubois District | 107 |
| Bighorn NF - Powder River District | 107 |
| Umpqua NF - Diamond Lake Visitor Center | 106 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Olympic NF - Main Office | 83 |
| Carson NF - Main Office | 71 |
| Malheur NF - Emigrant Creek District | 67 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Clearwater NF - Main Office | 55 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 53 |
| Mt Hood NF - Zigzag District | 53 |
| Umpqua NF - North Umpqua District | 51 |
| Coconino NF - Red Rock Visitor's Center | 50 |
| Lewis & Clark NF - Main Office | 47 |
| Colville NF - Republic District | 40 |
| Pike & San Isabel NF - South Platte District | 35 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Bighorn NF - Main Office | 30 |
| Coconino NF - Red Rock District | 29 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 28 |
| Black Hills NF - Mystic District | 28 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| Shasta-Trinity NF - Main Office | 27 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Tonto NF - Main Office | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 21 |
| Tonto NF - Mesa District | 20 |
| Washington & Jefferson NF - Lee District | 20 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 19 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Sequoia NF - Main Office | 17 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Carson NF - El Rito Station | 17 |

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|---|---|
| Fishlake NF - Fillmore District | 17 |
| Coronado NF - Main Office | 16 |
| Kaibab NF - North Kaibab District | 15 |
| Prescott NF - Bradshaw District | 15 |
| Humboldt-Toiyabe NF - Main Office | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Sawtooth NF - Fairfield District | 13 |
| Caribou-Targhee NF - Westside District | 12 |
| Santa Fe NF - Main Office | 11 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 11 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Tonto NF - Cave Creek District | 11 |
| Sawtooth NF - Main Office | 9 |
| Fishlake NF - Main Office | 8 |
| Manti-La Sal NF - Main Office | 8 |
| Black Hills NF - Main Office | 8 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 8 |
| Six Rivers NF - Mad River District | 8 |
| Idaho Panhandle NF - Coeur d'Alene River District | 8 |
| Gifford Pinchot NF - Main Office | 7 |
| Kaibab NF - Williams District | 7 |
| Humboldt-Toiyabe NF - Bridgeport District | 7 |
| Sawtooth NF - Minidoka District | 6 |
| Coconino NF - Mogollon Rim District | 6 |
| Fishlake NF - Fremont River District | 6 |
| White River NF - Dillon District | 5 |
| Bighorn NF - Medicine Wheel/Paintrock District | 5 |
| Kaibab NF - Main Office | 5 |
| Coconino NF - Main Office | 5 |
| Flathead NF - Tally Lake District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| Willamette NF - McKenzie River District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Prescott NF - Chino District | 4 |
| Colville NF - Newport District | 4 |
| Uinta-Wasatch-Cache NF - Evanston District | 3 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Inyo NF - Mammoth Lakes Center | 3 |
| Okanogan-Wenatchee NF - Cle Elum District | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Klamath NF - Main Office | 3 |
| Crooked River National Grasland | 3 |
| Malheur NF - Main Office | 3 |
| Mt Hood NF - Clackamas River District | 3 |
| Payette NF - McCall District | 3 |

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| | |
|---|---|
| Okanogan-Wenatchee NF - Main Office | 3 |
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| Angeles NF - Main Office | 3 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Fishlake NF - Beaver District | 2 |
| Idaho Panhandle NF - Main Office | 2 |
| San Juan NF - Dolores District | 2 |
| San Bernardino NF - Main Office | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Coronado NF - Douglas District | 2 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| Green Mountain NF - Middlebury Station | 2 |
| Willamette NF - Detroit District | 2 |
| Nez Perce NF - Main Office | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Helena NF - Helena District | 2 |
| Kaibab NF - Tusayan District | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Rogue River - Siskiyou NF - Wild Rivers District | 1 |
| Croatan NF - Main Office | 1 |
| Colville NF - Three Rivers District | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Mendocino NF - Main Office | 1 |
| Gallatin NF - Hebgen Lake District | 1 |
| Payette NF - New Meadows District | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Sam Houston NF | 1 |
| Green Mountain NF - Main Office | 1 |
| San Juan NF - Pagosa District | 1 |
| White Mountain NF - Saco District | 1 |
| Sawtooth NF - Stanley District | 1 |
| Sierra NF - Main Office | 1 |
| Cleveland NF - Trabuco District | 1 |
| Umatilla NF - Main Office | 1 |
| Tahoe NF - Main Office | 1 |
| Sawtooth NF - Ketchum District | 1 |
| Beaverhead-Deerlodge NF - Main Office | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| Six Rivers NF - Orleans District | 1 |
| Angeles NF - San Gabriel River District | 1 |

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| | |
|---|---|
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Routt NF - Parks Walden District | 1 |
| Uinta-Wasatch-Cache NF - Logan District | 1 |
| Umatilla NF - Walla Walla District | 1 |
| Rogue River - Siskiyou NF - Gold Beach District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Siuslaw NF - Main Office | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Umpqua NF - Cottage Grove District | 1 |
| Ottawa NF - Visitor Center | 1 |
| San Juan Public Lands Center - FS | 1 |
| Los Padres NF - Main Office | 1 |
| Grey Towers National Historic Site | 1 |
| **FWS** | **1,582** |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 250 |
| Arthur R. Marshall Loxahatchee NWR | 231 |
| Sam D. Hamilton Noxubee NWR | 213 |
| J.N. "Ding" Darling National Wildlife Refuge | 182 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| St. Marks National Wildlife Refuge | 104 |
| Merritt Island National Wildlife Refuge | 83 |
| DeSoto National Wildlife Refuge | 66 |
| Bombay Hook National Wildlife Refuge | 65 |
| Nisqually NWR | 39 |
| Sacramento NWR | 36 |
| Two Rivers National Wildlife Refuge | 25 |
| Fish and Wildlife Service Regional Office | 18 |
| Chincoteague NWR | 17 |
| Back Bay NWR | 16 |
| Don Edwards San Francisco Bay NWR | 9 |
| National Elk Refuge | 9 |
| Parker River National Wildlife Refuge | 3 |
| Ottawa National Wildlife Refuge | 3 |
| Bosque del Apache NWR | 1 |
| Ridgefield NWRC | 1 |
| **NPS** | **55,424** |
| Assateague Island National Seashore | 4,755 |

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**2.2%**

**78.7%**

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| | |
|---|---|
| Colonial National Historical Park | 3,246 |
| San Juan National Historic Site | 2,795 |
| Yosemite National Park | 2,374 |
| Chamizal National Memorial | 2,132 |
| Chesapeake & Ohio Canal NHP | 2,024 |
| Fort McHenry National Monument | 1,970 |
| Mount Rainier National Park | 1,891 |
| Indiana Dunes National Lakeshore | 1,702 |
| Lake Mead National Recreation Area | 1,650 |
| Hopewell Culture National Historical Park | 1,644 |
| Cuyahoga Valley National Park | 1,326 |
| Grand Canyon National Park | 1,186 |
| Acadia National Park | 1,133 |
| Richmond National Battlefield Park | 1,081 |
| Rocky Mountain National Park | 1,040 |
| Joshua Tree National Park | 958 |
| Zion National Park | 929 |
| Garfield National Historic Site | 926 |
| Petroglyph National Monument | 878 |
| Great Falls Park | 861 |
| Yellowstone National Park | 801 |
| Cedar Breaks National Monument | 743 |
| Arches National Park | 737 |
| Walnut Canyon National Monument | 733 |
| Catoctin Mountain Park | 688 |
| Death Valley National Park | 663 |
| Colorado National Monument | 637 |
| Harpers Ferry National Historical Park | 584 |
| Sequoia & Kings Canyon National Park | 523 |
| Organ Pipe Cactus National Monument | 466 |
| San Francisco Maritime National Historical Park | 452 |
| Channel Islands National Park | 450 |
| Montezuma Castle National Monument | 413 |
| Blue Ridge Parkway (Campgrounds) | 412 |
| Olympic National Park | 379 |
| Lewis & Clark National Historical Park | 359 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 341 |
| Bryce Canyon National Park | 337 |
| Big South Fork National River & Recreation Area | 313 |
| Wright Brothers National Memorial | 294 |
| Everglades National Park | 286 |
| Casa Grande Ruins National Monument | 276 |
| Big Thicket National Preserve | 265 |
| Sleeping Bear Dunes National Lakeshore | 242 |
| Petrified Forest National Park | 232 |

241 from SAAN including 120 from 2015/2016 exchanges

91 entered by BISC on 12/7

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| | |
|---|---|
| Dinosaur National Monument (Passes only sold at UT location)) | 222 |
| Shenandoah National Park - Thornton Gap Entrance | 221 |
| Grand Teton National Park | 219 |
| Pinnacles National Monument | 216 |
| Pu'uhonua O Honaunau | 211 |
| Hawaii Volcanoes National Park | 209 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Castillo de San Marcos National Monument | 207 |
| Florissant Fossil Beds National Monument | 202 |
| Tonto National Monument | 192 |
| Badlands National Park | 186 |
| Fort Washington Park | 178 |
| Cabrillo National Monument | 177 |
| Crater Lake National Park | 175 |
| Shenandoah National Park - Front Royal Entrance | 172 |
| Glacier National Park | 163 |
| Shenandoah National Park - Swift Run Entrance | 162 |
| Fossil Butte National Monument | 161 |
| Carlsbad Caverns National Park | 146 |
| Lava Beds National Monument | 134 |
| Delaware Water Gap National Rec Area | 133 |
| Mesa Verde National Park | 130 |
| Jewel Cave National Monument | 120 |
| Bighorn Canyon National Recreation Area | 112 |
| Lassen Volcanic National Park | 111 |
| Hot Springs National Park | 111 |
| Fort Vancouver National Historic Site | 109 |
| Tumacacori National Historical Park | 105 |
| Little Rock Central High School NHS | 103 |
| Saguaro National Park | 102 |
| Canyonlands National Park | 100 |
| Greenbelt Park | 98 |
| Aztec Ruins National Monument | 96 |
| Chickamauga & Chattanooga National Military Park | 88 |
| Saint Gaudens National Historic Site | 85 |
| Big Bend National Park | 84 |
| Haleakala National Park | 83 |
| Antietam National Battlefield | 80 |
| Craters of the Moon National Monument | 76 |
| Great Sand Dunes National Park | 74 |
| Mammoth Cave National Park | 69 |
| Prince William Forest Park | 69 |
| Obed Wild and Scenic River | 68 |
| Shenandoah National Park - Rockfish Entrance | 64 |
| White Sands National Monument | 62 |

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| | |
|---|---|
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| Klondike Gold Rush National Historical Park | 60 |
| Sunset Crater Volcano National Monument | 58 |
| Gulf Islands National Seashore | 58 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Wind Cave National Park | 40 |
| Devils Tower National Monument | 40 |
| Steamtown National Historic Site | 39 |
| Golden Spike National Historic Site | 38 |
| Weir Farm National Historic Site | 37 |
| Timpanogos Cave National Monument | 36 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Bandalier National Monument | 32 |
| Canaveral National Seashore | 31 |
| Fort Union National Monument | 30 |
| Capitol Reef National Park | 29 |
| Padre Island National Seashore | 29 |
| Vicksburg National Military Park | 26 |
| Gila Cliff Dwellings National Monument | 26 |
| Lowell National Historical Park | 24 |
| Mount Rushmore National Memorial | 22 |
| Little Bighorn Battlefield National Monument | 20 |
| Whiskeytown National Recreation Area | 20 |
| Saratoga National Historical Park | 19 |
| Pipestone National Monument | 19 |
| Theodore Roosevelt National Park - South Unit | 18 |
| Edison National Historical Park | 17 |
| Scotts Bluff National Monument | 17 |
| Denali National Park & Preserve | 16 |
| Pipe Spring National Monument | 15 |
| Lincoln Boyhood National Memorial | 14 |
| Fort Moultrie National Monument | 14 |
| Fort Davis National Historic Site | 14 |
| Wilson's Creek National Battlefield | 13 |
| Great Smoky Mountains NP - Sugarland VC | 12 |
| Harry S Truman National Historic Site | 11 |
| Great Smoky Mountains NP - Oconaluftee Visitor's Center | 10 |
| Tuzigoot National Monument | 10 |
| Chaco Culture National Historical Park | 9 |
| Great Basin National Park | 8 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| Wupatki National Monument | 7 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 6 |
| Chickasaw National Recreation Area | 6 |

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| | |
|---|---|
| Ulysses S Grant National Historic Site | 6 |
| Natural Bridges National Monument | 5 |
| Herbert Hoover National Historical Site | 4 |
| Fort Necessity National Battlefield | 4 |
| Johnstown Flood National Memorial | 4 |
| Valles Caldera National Preserve | 3 |
| Great Smoky Mountain NP - Cades Cove Campground | 3 |
| Carl Sandburg Home National Historic Site | 3 |
| Great Smoky Mountains NP - Smokemont Campground | 3 |
| National Historic Oregon Trail Interpretive Center | 2 |
| Capulin Volcano National Monument | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Mississippi National River & Recreation Area | 2 |
| Isle Royale National Park | 2 |
| Pictured Rocks National Seashore | 1 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| **USACE** | **3,449** |
| Philpott Lake | 1,328 |
| Mississippi River Project | 607 |
| Proctor lake | 261 |
| Wappapello Lake | 180 |
| Carters | 175 |
| Sandy Lake Recreation Area | 162 |
| Woodruff-Seminole | 150 |
| John H. Kerr Dam and Reservoir | 112 |
| Gull Lake Recreation Area | 89 |
| Greers Ferry Lake | 60 |
| Englebright Lake | 59 |
| Falls Lake | 54 |
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Allatoona | 33 |
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Lake Shelbyville | 5 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| North Hartland Lake | 2 |
| Tioga-Hammond Lakes Project | 1 |
| Hensley Lake | 1 |
| Cowanesque Lake Project | 1 |
| Raystown Lake Project | 1 |
| Abiquiu Lake | 1 |
| Bay Model Visitor Center | 1 |
| Table Rock Lake | 1 |

**4.9%**

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| **Grand Total** | **70,436** |

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17-01174_011198;17-01174_011198;17-01174_011199

**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]; Leslie Richardson[leslie_a_richardson@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-02-28T11:06:54-05:00
**Importance:** Normal
**Subject:** Fwd: IA Pass Price recalibration - 02-27-2016 version
**Received:** 2017-02-28T11:07:29-05:00
Pricing of the Interagency Annual Pass 2017-02-27 - bl edits.docx

Hello everyone,
As noted below, thanks to Leslie and Christian's efforts we have a revised version of the Annual Pass Pricing Analysis to review. We can discuss a timeline for final edits and publication on our call this afternoon. Thanks! ...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

---------- Forwarded message ----------
From: **Christian Crowley** <christian_crowley@ios.doi.gov>
Date: Mon, Feb 27, 2017 at 6:23 PM
Subject: IA Pass Price recalibration - 02-27-2016 version
To: Brooke Linford <brooke_linford@nps.gov>
Cc: Leslie Richardson <leslie_a_richardson@nps.gov>

Greetings,

I've attached an updated version of the report that reflects the changes we discussed on our last calls:

- We've included more information on the non-NPS bureaus' data;

- We developed a 2007-2016 annual equivalent for the post-2014 price increase in NPS fees;

- Showed how an $80 Interagency pass price could have been adjusted for inflation since 2007;
- Listed changes in the senior pass under 2016 legislation;
- Adjusted how we describe BLM's participation in FLREA to "about … 10% of BLM sites" (per Dave Ballenger's suggestion); and
- Included a note about how USFS defines a "site", explaining that a single national forest may contain several "sites" for rec fee purposes.

For the USFS definition of a site, we relied on USFS publications. If the reviewers from USFS would prefer to see different language there, please feel free to send it along. We will be happy to make that change, and any other updates that reviewers come across.

Bye for now,

Christian

# Pricing of the Interagency Annual Pass: A Review of Existing Data and Analyses

Leslie Richardson[1] and Christian Crowley[2]

[1]Economist, National Park Service, Social Science Program, leslie_a_richardson@nps.gov, 970-267-7313
[2]Economist, Department of the Interior, Office of Policy Analysis, christian_crowley@ios.doi.gov, 202-208-3799

## Contents

## Executive Summary


The Interagency Annual Pass, which provides access to more than 2,000 federal recreation sites that charge an entrance fee or other day use fee, has been available at a price of $80 since 2007. The goal of this effort was to evaluate various sources of existing data and analyses to help inform potential changes in the price of the Annual Pass. Specifically, we looked at recent reviews and audits, agency revenues and pass sales, entrance and other site access fees, and a 2006 pricing analysis of the Interagency Annual Pass, which was updated in this report using current pass sales data.

Key findings indicate that a modest increase in the price of the Interagency Annual Pass may be warranted for the following reasons:

- If the Interagency Annual Pass were adjusted for inflation, the pass that cost $80 in 2007 would cost about $93 in 2016. The price of the pass has never been adjusted for inflation, meaning in real dollars, the pass is more than 10% cheaper than it was when it was introduced.
- As noted in the University of Wyoming's 2006 Interagency Annual Pass pricing study, whatever base price is chosen for the pass could be adjusted upward in advance to account for future increases in entrance fees. In reality, entrance fees at NPS sites increased by more than 40% once the moratorium on fee increases was lifted in 2014 (equivalent to a 3 to 5 percent increase per year since 2007), whereas the Interagency Annual Pass has remained at $80 since 2007.
- Based on an evaluation of recreation fee and revenue changes over time, it appears that visitation to NPS sites is relatively unresponsive to increases in entrance and other site access fees. A similar finding can be gleaned from our update of the University of Wyoming's 2006 pricing analysis. As a result, increasing the price of the Interagency Annual Pass up to $90 or even $95 is not expected to greatly reduce demand or pass revenues, and it should serve to increase total revenues and reduce 'foregone' revenues in aggregate across all agencies participating in the pass program.

Of course, numerous objectives have to be balanced when evaluating the price of the Interagency Annual Pass. For instance, a higher price is likely to increase total revenues, but may discourage visitation to federal lands relative to a lower pass price, especially if entrance fees also continue to increase. This raises questions of what represents a 'fair' pass price, in terms of maintaining affordable access to federal recreation sites. In addition, it was beyond the scope of this study to evaluate any indirect effects of increasing the price of the pass (such as reduced visitor crowding), or the distributional effects of pricing changes on individual agencies. Finally, this effort evaluated existing data and analyses only. A new

comprehensive study of the Interagency Annual Pass could be undertaken to determine people's satisfaction with the current pass, assess their motivations for buying the pass, and conduct a more accurate and updated pricing analysis.

## Introduction

In 2007, the Interagency Annual Pass, also referred to as the "America the Beautiful – the National Parks and Federal Recreational Lands Pass," was made available to the public, replacing the Golden Eagle and National Parks Passes. The pass covers entrance and standard amenity fees at federal recreation sites managed by the National Park Service, Fish and Wildlife Service, the Forest Service, Bureau of Land Management, Bureau of Reclamation, and the U.S. Army Corps of Engineers. In selecting a price for the pass, the goal was to charge a price that made sense in economic terms, was defensible and understandable to decision makers and the public, and would not cause total revenues across all agencies to be less than total revenues in the absence of the pass program. In addition, the price should take into account people's willingness-to-pay for the convenience of using the pass and any altruistic motives they may have. An economic analysis conducted by the University of Wyoming (described in greater detail below) was used to help select a price for the Interagency Annual Pass. Ultimately, the price was set at $80 in 2007 and has not changed since.

Now that the pass has been available for ten years, various sources of existing data can be evaluated and updated to help inform potential changes in the price of the pass. For instance, national park visitors typically have three ways to access sites that charge a day use fee: use the Interagency Annual Pass, pay the daily entrance fee, or use an annual pass that covers entrance to that particular park only. Although the price of the Interagency Annual Pass has not changed, looking at changes in the price of the other two 'substitutes' can provide some insight into how responsive visitors are to price changes. In addition, the University of Wyoming's 2006 pricing analysis can be updated using recent sales data for the Interagency Annual Pass. The overall goal of this effort is to provide information from multiple sources to help policymakers evaluate alternative prices for the pass.

The remainder of this report is outlined as follows. First, background information is provided, including the history of fees under FLREA, history of the Interagency Pass, a summary of the University of Wyoming's 2006 pricing analysis, as well as a summary of recent reports on NPS recreation revenues. Next, an analysis of agency-level revenue, visitation, and entrance fee data is provided. An update to the

University of Wyoming's 2006 pricing analysis is then presented, followed by recommendations for future study.

## Background

Federal recreation sites in the United States annually host hundreds of millions of visitors, including for 2015:

- 370 million visits to Army Corps of Engineers areas;[1]
- 307 million visits to National Park Service sites;[2]
- 188 million estimated visits to National Forest System sites;[3]
- 62 million estimated visits to Bureau of Land Management sites;[4]
- 48 million estimated visits to National Wildlife Refuges;[5] and
- 28 million estimated visits to Reclamation sites.[6]

Recreation facilities and opportunities at many of these sites are funded in part by visitors, through revenue collected under the Federal Lands Recreation Enhancement Act (FLREA). FLREA revenue, in the form of on-site fees and pass sales, is an important funding source for federal lands management, along with Congressional appropriations, donations, rents, commercial use fees, etc.

### History of Fees under FLREA

The National Recreation Fee Demonstration Program was created in 1996 as a three-year pilot program. This was followed by FLREA in 2004. Under FLREA federal land management agencies are authorized to collect fees from visitors, and to use those fees to develop and maintain public recreation sites. Participating agencies include the Department of the Interior's (DOI's) Bureau of Land Management (BLM), Bureau of Reclamation (Reclamation), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS); and the U.S. Department of Agriculture's (USDA's) Forest Service (USFS). The U.S.

[1] Annual average, from http://www.usace.army.mil/Missions/Civil-Works/Recreation/
[2] NPS Annual Visitation Summary Report for 2015 https://irma.nps.gov/Stats/SSRSReports/National%20Reports/Annual%20Visitation%20Summary%20Report%20(1979%20-%20Last%20Calendar%20Year)
[3] https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf
[4] BLM Public Land Statistics, FY 2015, Table 4-1. https://www.blm.gov/public_land_statistics/pls15/pls2015.pdf
[5] DOI data.
[6] DOI data

Army Corps of Engineers (USACE) was authorized to join the FLREA pass program in the 2014 Water Resources Reform and Development Act.[7]

FLREA authorizes the agencies to charge several types of fees:

- NPS and FWS charge *entrance fees* at sites like National Parks and Wildlife Refuges;
- BLM, USFS, and Reclamation charge *standard amenity recreation fees* at sites like picnic areas and interpretive sites;
- Agencies collect *expanded amenity recreation fees* for enhanced services such as a cabin rental, campgrounds, and boat launch facilities; and
- *Special Recreation Permits* for activities such as off-highway vehicle use, guiding, and events.

In deciding whether to establish or change fees at federally managed sites, the agencies engage with the public and stakeholders to ensure that the different perspectives are considered and that the fees are appropriate. Fees are currently charged at about 45% of NPS sites, 32% of USFS sites,[8] 10% of BLM sites, 7% of FWS refuges, and a single Reclamation site. FLREA fee revenue has increased steadily from $196 million in Fiscal Year (FY) 2005 to $278 million in FY 2014 (DOI and USDA, 2015).

## NPS Entrance Fees Study (2001)

McKinsey & Co (2001) completed a study of NPS entrance fees finding that prices were not standardized across the nation. The authors recommended developing a national model to determine prices. In 2006, NPS implemented a model updating prices for entrance fees (per-person, per-vehicle, and per-motorcycle) and single-park annual passes. NPS sites were divided into four groups, based on type of site and visitation levels:

- Group 4 includes the nine most-visited parks (Bryce, Glacier, Grand Canyon, Grand Teton, Rocky Mountain, Sequoia-Kings, Yellowstone, Yosemite, Zion);
- Group 3 includes all other National Parks;
- Group 2 includes the more visited non-Park unit-types (e.g., Seashores, Monuments);
- Group 1 includes the less visited non-Park unit-types (e.g. National Battlefields, Parkways)

[7] Since the enactment of FLREA, interagency passes have been accepted at certain sites managed by the U.S. Army Corps of Engineers (USACE) and Tennessee Valley Authority.
[8] USFS manages wilderness areas; 155 national forests; 22 national grasslands; 20 national recreation areas; 9 national scenic areas; and 7 national monuments, volcanic monuments, and national preserves (CRS, 2014; USFS, 2016b). Any of these units may contain a number of "sites" as defined by USFS, including a variety of recreation facilities, including hiking trails, campgrounds, alpine ski areas, picnic areas, boating sites, and swimming areas.

The 2006 model was initially implemented at 34 NPS units. In 2008 the National economy entered a recession, and NPS implemented a moratorium on increasing fees. In 2014, NPS lifted the moratorium and started applying fee increases using the updated pricing structure shown in Table 1. Proposed fee changes at an NPS site are subject to public review and comment through the "civic engagement" process. Proposed fees are reviewed by the Executive Committee and must be approved by the NPS National Leadership Council (NLC).

**Table 1. National Park Service Target Entrance Fees Based on Pricing Model (2014 Update)**

| Group | Site Types | Single-Park Annual Pass | Per Vehicle | Per Person | Motor-cycle |
|---|---|---|---|---|---|
| 1 | National Historic Sites, National Military Parks, National Battlefield Parks, National Memorials/Shrines, National Preserves, and Parkways | $30 | $15 | $7 | $10 |
| 2 | National Seashores, National Recreation Areas, National Monuments, National Lakeshores, and National Historic Parks | $40 | $20 | $10 | $15 |
| 3 | National Parks (most of the parks) | $50 | $25 | $12 | $20 |
| 4 | National Parks (certain parks, e.g., Grand Canyon) | $60 | $30 | $15 | $25 |
| | Increase over 2006 Fees | $10 | $5 | $2,$3 | $5 |
| | Equivalent annual % increase | 2%-5% | 2%-5% | 2%-5% | 3%-9% |

Sources: DOI and USDA (2015); GAO (2015)

**Commented [LB1]:** Why USDA?

## History of the Interagency Pass under FLREA

Prior to FLREA, various federal recreation sites accepted a variety of passes, including the Golden Eagle Passport, Golden Age Passport, Golden Access Passports, and the National Parks Pass. FLREA authorized a new interagency pass family called the "America the Beautiful - National Parks and Federal Recreational Lands Passes." Passes are sold at participating recreation sites, over the phone or online at websites like store.usgs.gov (so-called *central sales*), at third-party vendors (e.g., outdoors outfitters), and at certain agency offices. The agencies currently offer a variety of interagency passes accepted at FLREA sites around the country:

- An $80 Annual Pass;

- A $10 lifetime Senior Pass for those 62 and older;[9]
- A free Every Kid in a Park Pass for 4th graders;
- A free Access Pass for those with permanent disabilities;
- A free Annual Military Pass for members of the military and their families; and
- A free Volunteer Pass for those who volunteer 250 hours on public lands.

The agencies also have occasional fee-free days for the general public.

FLREA requires the agencies to report to Congress every three years on implementation of the recreation fee program. The 2015 Triennial Report shows that pass sales have continued to increase, up to nearly one million passes annually. As shown in Table 2, for FY 2012 through FY 2014 over 80 percent of sales were made at NPS sites, with a further 8 or 9 percent of the total sold at USFS sites, and the remaining 10 or 11 percent sold at sites managed by other agencies. Of the total passes sold, about two-thirds are for the $10 Senior Pass, and one-third are for the $80 Annual Pass.

**Table 2. Proportion of Interagency Passes Sold, by Agency and Pass Type**

| | FY 2012 | | FY 2013 | | FY 2014 | |
|---|---|---|---|---|---|---|
| NPS pass sales | 763,124 | 81% | 792,062 | 82% | 798,683 | 80% |
| USFS pass sales | 84,093 | 9% | 80,298 | 8% | 81,007 | 8% |
| Other Agency pass sales | 92,158 | 10% | 98,873 | 10% | 113,341 | 11% |
| Pass Types (All Agencies) | | | | | | |
| Annual Passes | 314,835 | 34% | 329,530 | 34% | 356,016 | 36% |
| Senior Passes | 624,540 | 66% | 641,703 | 66% | 637,015 | 64% |
| Total Passes | 939,375 | 100% | 971,233 | 100% | 993,031 | 100% |

Source: DOI and USDA (2015)

There was a dramatic increase in pass sales in FY 2015, leading up to the 2016 NPS Centennial. In FY 2015, NPS sites saw a 33 percent increase in the level of Annual Passes sold, compared to FY 2014. USFS sites saw a similar increase in Senior Passes sold over the same period (though only a 4 percent increase for Annual Passes), and FWS reported a 25% increase in all Interagency Passes sold. Central and

[9] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

third party sales saw an increase of over 45 percent (though these sources typically make up about 2 percent of pass sales).[10]

Pass-holders gain free entry to many recreational sites managed by federal agencies, however there is no centralized tracking system available to determine where and when the passes are used. In 2016 NPS published "The National Parks and Federal Recreational Lands Pass Survey," reporting the results of a survey of pass use among pass-holders who purchased an Annual Pass through central sales via the USGS website (rather than in person, at a recreation site). The repeat contact mail survey had a final response rate of 43.5%, with 772 completed surveys returned. The survey asked respondents to recall the last five times they had used their pass to access a recreation site.[11] Overall, approximately 85% of Annual Pass use was reported to be at NPS sites, and about 8% at USFS sites. Reclamation, BLM, and USFWS sites saw 2% or less of reported pass uses (Bioeconomics, 2016).

The price of the Interagency Annual Pass has remained at $80 since it was first introduced in 2007. Table 3 shows what the price of the pass would be each year if it kept pace with inflation.

**Table 3. Price of the Interagency Annual Pass if Adjusted for Inflation**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Pass Price | $83.07 | $82.78 | $84.13 | $86.79 | $88.59 | $89.88 | $91.34 | $91.45 | $92.60 |

## Summary of the University of Wyoming's 2006 Pricing Analysis

In 2005, the U.S. Department of Agriculture and the Department of the Interior issued a request for proposals to evaluate possible prices for the new Interagency Annual Pass. A project proposal submitted by the University of Wyoming, through its Wyoming Survey and Analysis Center, was selected to provide the requested assistance. The project consisted of five main tasks:

1. The production of a roadmap detailing the steps that would be taken to complete the remaining tasks;

[10] Data from DOI and USDA, in personal communications.
[11] The survey also asked about 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

2. A benchmarking study used to compare existing federal recreation passes with state and Parks Canada passes;
3. An examination of theoretical and methodological issues in the economics of non-market valuation;
4. Focus groups; and
5. A national telephone survey.

The overall goal of the project was to provide information from multiple sources that could assist policymakers in determining a price for the new Interagency Annual Pass. The national telephone survey in particular provided comprehensive information on the number of households that would be expected to purchase the pass at various prices. This information was then used to forecast revenues from the sale of the pass, as well as gate revenues, across all agencies at various pass prices. In addition, the request for proposals stipulated that the price of the pass "should at least allow the government to break even in the sense that, on average, the sale of the pass does not result in a loss of revenue relative to the revenue that would be received absent the ability to purchase an annual pass." To address this, the researchers also evaluated foregone revenue (total revenues in the absence of the pass program minus total revenues with the pass program) at various pass prices. They determined that the price of the pass would need to be set at $125 or above to come close to revenue neutrality, assuming gate entrance fees remained at their current level. At the time of the study, $125 was equal to the cost of an annual pass for California's state parks, and was less than the price of an annual pass for Parks Canada. A novel addition to their analysis was the use of Golden Eagle and National Parks Pass sales data to calibrate hypothetical willingness-to-pay values with real choices. Now that the Interagency Annual Pass has been available for the last ten years, this calibration can be updated using current data on the number of passes sold at a price of $80. This will provide some indication of how pass sales and associated revenues might be expected to change at different pass prices. The details of this analysis are presented later in this report.

## Recent Reports on NPS Recreation Revenues

This section focuses on the National Park Service, though the conclusions are generally applicable across all FLREA agencies. GAO (2015) found that total funding for the National Park Service (NPS) has not kept pace with inflation in recent years, making FLREA revenue an increasingly important part of total NPS funding. Recognizing this increasing importance, GAO recommended that NPS periodically review entrance fees for potential updates. GAO also recommended amendments to FLREA so that the federal agencies can adjust pass prices, in particular the $10 lifetime Senior Pass.

OIG (2015) examined opportunities for the National Park Service (NPS) to increase its recreation program revenues, focusing on the three largest sources of recreation revenues: park-unit entrance fees, interagency passes, and commercial bus tour fees. OIG recommended that NPS establish intervals for periodic reviews to ensure that prices for these three revenue sources remain up to date. In particular, OIG recommended updating the price of the $80 Annual Pass.[12]

## Agency-level Study

This section summarizes data on FLREA revenues collected by the agencies in recent years.

### National Park Service (NPS)

NPS service-wide revenues from the sale of single-park annual passes, the Interagency Annual Pass, and daily admission/entrance fees from 2007 to 2016 are shown in Figure 1. In general, revenues from all sources have seen large increases since 2014, both in nominal dollars and after adjustment for inflation. Revenue from the sale of single-park annual passes has increased by about 25% since 2014, revenue from the sale of the Interagency Annual Pass has increased by nearly 70%, and revenue from entrance fees has increased by about 45%. This boost in revenues is partly due to increased visitation to NPS sites, which could be related to the 2016 NPS Centennial and efforts such as the 'Find Your Park' campaign. Although finalized 2016 visitation data are not yet available, many parks are already reporting record-breaking visitation.

[12] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

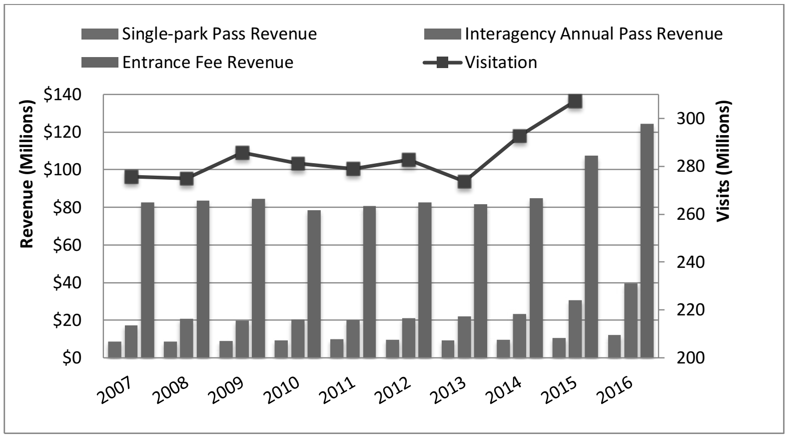


Figure 1. NPS Service-wide Revenues and Visitation, 2007-2016

## U.S. Fish and Wildlife Service (FWS)

Data for FY 2013 through FY 2015 show that FWS visitation and fee revenues followed a similar pattern to that of NPS, though with a less dramatic increase in FY 2015 (Figure 2). However, in FY 2016 FWS saw a drop in fee revenues, as opposed to NPS' continued increase.

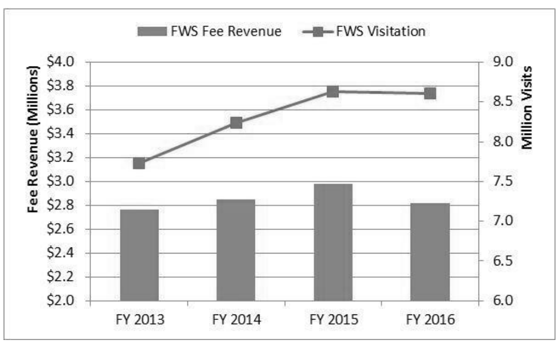


Figure 2. FWS Fee Revenue and Visitation, FY13-FY16 (34 Sites)

### Bureau of Land Management (BLM)

As shown in Figure 3, BLM has seen about a 7 percent increase in visitation over the past four years, from an estimated 58 million visits in FY 2013 to more than 62 million visits in FY 2016. Meanwhile, standard amenity fee revenues have increased by nearly 20 percent.[13]

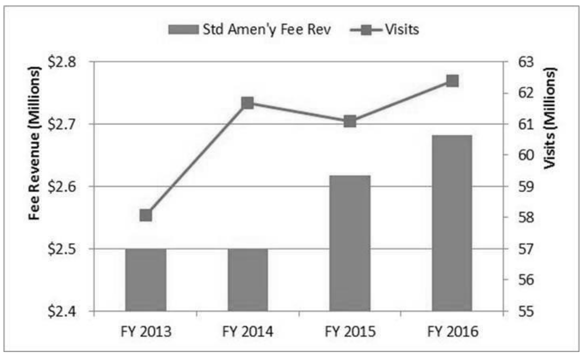


Figure 3. BLM Fee Revenue and Visitation, FY 2013 – FY 2016

Figure 4 shows sales of the Interagency Pass at BLM sites. The $80 Annual Pass saw a steady increase from 3,858 passes in FY 2012 to 7,506 in FY 2015. This was followed by a fall to 5,511 passes sold in FY 2016. This may be an effect of the NPS Centennial in 2016, with more BLM site users also visiting NPS sites, and purchasing their passes at those sites. In contrast, sales of the senior pass have continued to increase, from 16,186 in FY 2012 to 21,497 in FY 2015, and 22,722 in FY 2016.

[13] Source: BLM Public Land Statistics (PLS). Other forms of fee revenue reported by BLM in PLS include expanded amenity fee permits; special area permits; commercial competitive, group, and event permits; and leases.

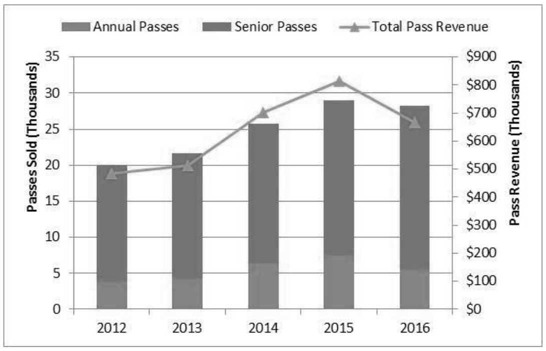


Figure 4. Annual and Senior IA Passes Sold at BLM Sites (2012-2016)

## U.S. Forest Service (USFS)

National forests received nearly 150 million visits in FY 2015.[14] As shown in Figure 5, USFS sold an increasing number of both Annual and Senior Passes in FY 2015 and FY 2016. Senior Passes make up the majority of passes sold by USFS: 78% in FY 2015 and FY 2016. This is comparable to BLM's pass sales, where Senior Passes made up 74% of the total in FY 2015 and 80% in FY 2016.

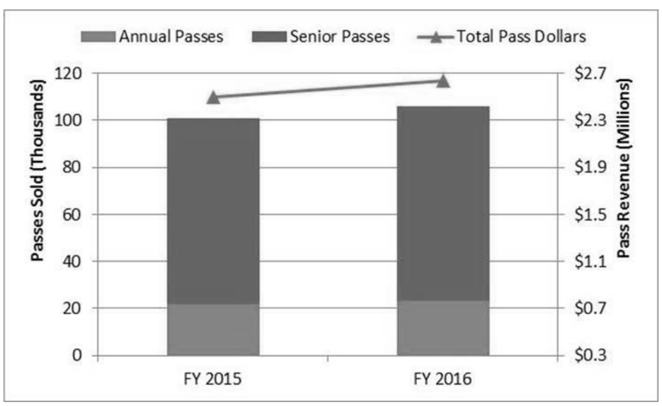


Figure 5. Annual and Senior IA Passes Sold at USFS Sites (2015, 2016)

[14] The USFS National Visitor Use Monitoring (NVUM) program aims to survey visitation at all USFS units once every five years. No unit has yet been surveyed enough times to allow for reporting on trends or use patterns. [Source: US Forest Service (2015) National Visitor Use Monitoring Survey Results; Data Collected FY 2011 through FY 2015 https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf].

USFS makes a relatively large proportion of their fee revenue from sales of passes for particular USFS sites, such as multi-day, weekly, season, annual and "grand annual" passes; and passes for a household or vehicle; and "joint" passes such as the $50 joint pass covering both Arapaho National Recreation Area and Rocky Mountain National Park. FY 2016 fee and pass revenue data for 73 National Forests included prices for daily use fees and/or passes for 60 of these 73 National Forests, and an additional 14 USFS units that charge fees. Out of these 74 units, 72 charge a daily use fee,[15] and 45 units offer an annual pass. Table 4 summarizes USFS fees and pass prices for FY 2016.

**Table 4. USFS Fees Summary (FY 2016)**

| Revenue Source | Type of Fee/Pass | Price | # of Units Offering |
|---|---|---|---|
| Day Use Fees | per person | $2-$12 | 72 |
| | per bicycle | $3 | 1 |
| | bus | $10 | 1 |
| Passes | per person | $2-$12 | 72 |
| | per bicycle | $3 | 1 |
| | bus | $10 | 1 |
| | 3-day | $10 | 2 |
| | 7-day | $15-$20 | 2 |
| | week | $10-$15 | 5 |
| | season | $40 | 1 |
| | seasonal | $25 | 1 |
| | season/off season | $30/$20 | 1 |
| | annual | $15-$80 | 45 |
| | grand annual | $40 | 1 |
| | vehicle | $18-$20 | 1 |
| | household | $25-$45 | 2 |

Source: UFSF data.

[15] Two of these units charge a one-time fee that allows several days of use: White River, and Uinta-Wasatch-Cache.

As shown in Figure 6, for FY 2016, about three-quarters of fee revenue came from such single-site passes, with the remaining quarter coming from amenity fees deposited by visitors in on-site fee-deposit vaults, or "fee tubes."

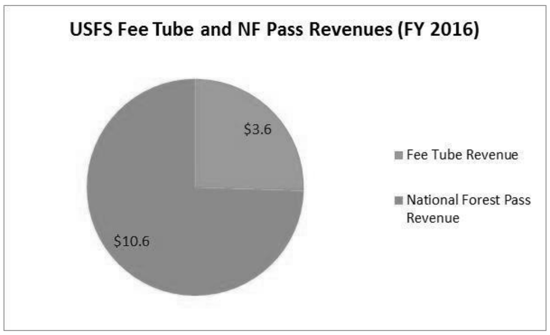


Figure 6. USFS Revenues (FY 2016)

## U.S. Army Corps of Engineers (USACE)

The U.S. Army Corps of Engineers (USACE) joined the Interagency Pass Program in 2016, adding recreational opportunities at USACE's 403 lakes and river projects in 43 states. As shown in Figure 7, visitation at USACE sites ranged from 330 million to 362 million over 2007 to 2012, making USACE the agency with the largest visitation. Unlike USFS, USACE receive most of their revenue in day use fees, rather than in USACE passes: 11 to 13 percent during 2007 to 2015, compared to USFS's 75 percent for 2016.

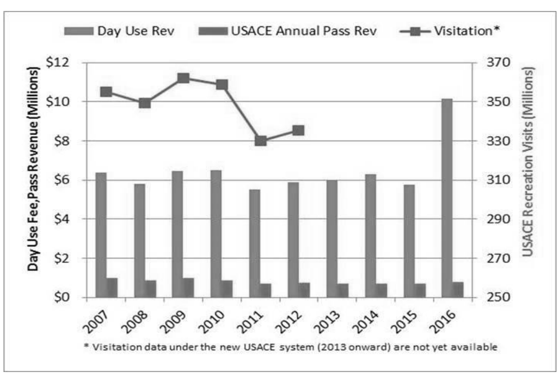


Figure 7. USACE Revenues and Visitation, 2007-2016

## Fee Prices Charged at Sites

In addition to trends in total revenues and visitation, prices represent another important piece of information. There is some variety in how entrance fees and amenity fees are set by the different agencies. For example, as shown in 4, USFS fees vary by site, length of time, and season. FWS fees charged at 34 refuges include single-site annual passes ranging from \$10 to \$30, and daily per-vehicle fees ranging from \$2 to \$8.[16] The US Army Corps of Engineers (USACE) joined the FLREA agencies on January 1, 2016, and at this time they raised their per-vehicle fee from \$2.50 to \$5, and the price of their USACE annual pass from \$30 to \$40.[17]

We considered the relationship between visitation and entrance/standard amenity fees. For USFS we considered daily fees for 49 National Forests for which we had visitation figures. In FY 2016, there was relatively low correlation (a Pearson's correlation coefficient of 0.15) between daily fees and visitation. For FWS data from FY 2013 to FY 2016, there is a positive correlation between visitation and fee levels: about 0.46 for daily entrance fees, and 0.55 for annual fees, over the four-year period, indicating that more popular refuges tend to have higher fees. This correlation seems to be growing stronger over time; in the absence of price changes this indicates that popular refuges are becoming more popular.

We were able to obtain detailed data on access fees for NPS sites. Although the price of the Interagency Annual Pass has remained at \$80, park entrance fees and the price of single-park annual passes have changed over time, especially after the moratorium on fee increases was lifted in 2014. For those parks that charge an entrance fee, Figure 8 shows the average per-person and per-vehicle entrance fee charged from 2007 to 2016, as well as the average price of single-park annual pass for those parks that offer such passes.

[16] Kaua'i NWR Complex charges \$5 per person, rather than a per-vehicle fee.
[17] Future research will examine how these price changes impacted visitation at USACE sites.

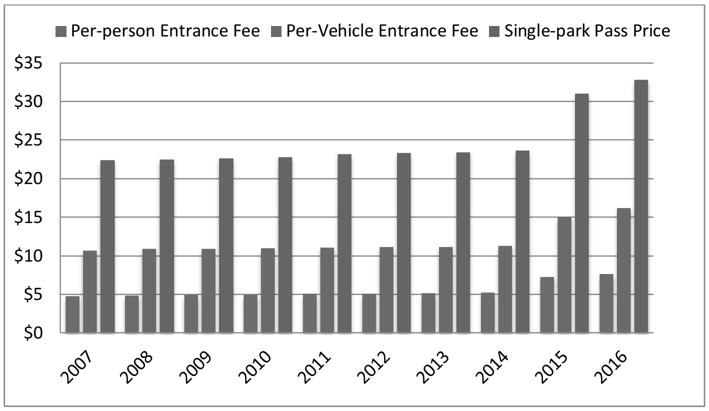


**Figure 8. Average Per-Person Entrance Fee, Per-Vehicle Entrance Fee, and Individual Single-Park Pass Price (NPS Sites, 2007-2016)**

Over that time period, per-person entrance fees increased by about 60% on average (39% when adjusted for inflation), and per-vehicle entrance fees have increased by more than 50% (31% when adjusted for inflation). Just since 2014, per-person and per-vehicle entrance fees have increased by more than 40% on average. The average price of a single-park annual pass has increased by about 45% since 2007 (25% when adjusted for inflation) and by more than 35% since 2014. The large increases since 2014 are a result of NPS lifting the moratorium that year and applying fee increases using the updated pricing structure shown in Table 1. As shown in Table 5, the equivalent annual percentage increase in entrance fees and single-park pass prices from 2007 to 2016 would be about 3 to 5 percent.

**Table 5. NPS Average Entrance Fees**

| | Per-Person Entrance Fee | Per-Vehicle Entrance Fee | Single-Park Annual Pass |
|---|---|---|---|
| Average in 2007 | $4.74 | $10.63 | $22.37 |
| Average in 2016 | $7.65 | $16.16 | $32.82 |
| Percentage increase from 2007 to 2016 | 61% | 52% | 47% |
| Percentage increase from 2007 to 2016, adjusted for inflation | 39% | 31% | 26% |
| Equivalent annual % increase | 4%-5% | 3%-5% | 3%-4% |

There are two important takeaways from this review of recreation fees and revenues over time:

- At least for NPS sites, visitation appears to be relatively unresponsive to price increases associated with site access. There have been large increases in the average price of entrance fees and single-park passes, and revenues across all sources have continued to increase, both in nominal and real dollars. This is consistent with previous findings that entrance fees alone are not a barrier to more frequent visitation of NPS units (Ostergren et al., 2005; Factor, 2007). Of course, entrance and other site access fees typically represent only a small portion of the total trip cost that must be considered when making the decision to visit a recreation site. Further study of the relationship between visitation and access fees for other federal lands could be informative, for example, evaluating visitation data for USACE before and after this agency joined the Interagency Annual Pass program.
- The University of Wyoming's 2006 pricing analysis for the Interagency Annual Pass (discussed in greater detail below) highlighted the fact that whatever base price was ultimately chosen for the pass could be adjusted in advance to account for future increases in gate fees. They explain that while the pass might realistically see cost of living adjustments every three years or so, gate fees could increase more often than that. Assuming that average gate fees increase by 10% over a three-year period, the Interagency Annual Pass would need to include a 10% premium at the outset to ensure that it satisfies revenue neutrality. In reality, while entrance fees across the National Park System (and possibly other federal lands) have increased significantly over the last few years, the price of the Interagency Annual Pass has remained at $80.

## Updating the University of Wyoming's 2006 Pricing Analysis

In 2006, researchers at the University of Wyoming completed an analysis to assist with pricing of the new Interagency Annual Pass (hereafter referred to as Aadland and Shogren, 2006). The basis of the analysis was a nationwide telephone survey administered to two independent strata: a nationally representative sample of U.S. households obtained through random digit dialing (RDD sample) and a random sample of households known to the National Park Foundation to have purchased a National Parks Pass between April 2004 and March 2005, which included mainly those households that purchased the pass online (NPF sample). The analysis is based on the assumption that an individual household will choose to buy the new Interagency Annual Pass if the benefits of doing so outweigh the costs. It is initially assumed that the primary motivation for purchasing the pass is based solely on its economic value; that is, people will purchase the pass if it reduces their expected costs associated with visitation to federal recreation sites.

The policymaker's decision is to choose the price of the pass to maintain revenue neutrality; i.e., total revenues across all agencies participating in the pass program will not be less than total revenues in the absence of the pass program.

To determine how much respondents would be willing to pay for the new Interagency Annual Pass, the study used a nonmarket valuation method known as Contingent Valuation (CV). After a short description of the new pass, households that had visited federal recreation lands in the last two years were presented with a dichotomous choice CV question in which they were asked if they would be willing to purchase the pass at a randomly selected price, ranging from $25 to $165. After responding 'yes' or 'no,' they were asked a follow-up CV question to more precisely determine their actual willingness-to-pay for the pass. If the respondent answered 'no' to the first price, they were presented with a lower price and asked if they would be willing to purchase the pass. If the respondent answered 'yes' to the first price, they were presented with a higher price and asked if they would be willing to purchase the pass. Using the results from this series of questions and scaling to the relevant population of potential pass purchasers, Aadland and Shogren (2006) were able to project the number of households that would be expected to purchase the pass at various prices. To do so, they rely on two different estimates:

1. Unconditional estimates – these estimates do not rely on any econometric model, but rather, are derived directly from households' responses to the two CV questions. For example, if a respondent said 'yes' to a pass price of $65, but 'no' to a pass price of $85, their true willingness-to-pay is assumed to be the midpoint of this interval, or $75. If a respondent said 'yes' to a pass price of $65 and 'yes' to a pass price of $85, they are assigned a willingness-to-pay value of the high price plus $10, or $95 in this example. Finally, if a respondent said 'no' to a pass price of $65 and 'no' to a pass price of $45, they are assigned a willingness-to-pay value equal to half of the lower price, or $22.50.

2. Conditional estimates – these estimates are derived from an econometric model, specifically, an interval regression model. There is a probability associated with each household's possible series of responses to the two CV questions – yes/yes, no/no, yes/no, and no/yes. These probabilities are used to create a log likelihood function, and the regression coefficients are then chosen to maximize this function. Predicted willingness-to-pay estimates for every household in the sample can then be calculated based on these results.

As with any application of the Contingent Valuation Method, survey respondents are asked to make a hypothetical purchasing decision. However, since they are not actually required to pay what they say they will, respondents may overstate their willingness-to-pay. To address this possible hypothetical bias, Aadland and Shogren (2006) used outside information on real market transactions to 'calibrate' their projected demand estimates. Specifically, revenues from the sale of the National Parks Pass and the Golden Eagle Pass were used to scale the projected Interagency Annual Pass revenues (and number of pass-holders, which is just total revenue divided by price) in an effort to better reflect the actual purchasing decisions of consumers. Now that we have ten years of sales data for the Interagency Annual Pass at a price of $80, we can use this information to update the external calibration for hypothetical bias and more accurately capture current demand for the pass. Across all agencies, sales of the Interagency Annual Pass from 2009 to 2014 were as follows:

**Table 6. Interagency Annual Passes Sold by Year and by Agency**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| BLM | 2,434 | 2,765 | 3,874 | 3,858 | 4,267 | 6,348 |
| FWS | 1,667 | 1,771 | 1,922 | 1,819 | 2,014 | 1,926 |
| NPS | 243,281 | 259,580 | 251,779 | 262,678 | 276,824 | 290,035 |
| BOR | 29 | 48 | 56 | 62 | 161 | 20 |
| USFS | 18,287 | 18,329 | 18,469 | 18,537 | 17,557 | 20,871 |
| Central Sales | 21,300 | 22,178 | 18,942 | 16,948 | 18,363 | 23,360 |
| Third Party | 3,144 | 6,387 | 7,842 | 10,933 | 10,344 | 13,456 |
| Total | 290,142 | 311,058 | 302,884 | 314,835 | 329,530 | 356,016 |

Based on the last three years that data are available, total Annual Pass sales have averaged around 333,460 per year at a pass price of $80. This price/quantity point is used to calibrate the unconditional and conditional demand estimates from Aadland and Shogren (2006). For instance, if their estimates predicted that there would be 450,000 passes demanded at a price of $80, but we know there were only 333,460 passes sold at a price of $80, then we divide the number of predicted passes demanded at each price by a factor of 1.35 (450,000/333,460). This is essentially shifting the entire demand curve to more accurately project the number of passes that could be expected to be sold at various prices. We focus on the RDD sample only since the NPF sample accounts for a very small and specific group of pass purchasers from 2006. As noted by Aadland and Shogren (2006), if the two samples were combined and weighted to reflect their relative population sizes, the combined results would be virtually indistinguishable from an analysis of the RDD sample alone.

As with most goods bought and sold in the marketplace, as the price of the pass increases, the quantity of passes demanded will decrease, all else constant. The extent of this decrease depends on how responsive people are to price changes, a relationship known as the *price elasticity of demand*. For a particular good, this elasticity is calculated as the percentage change in quantity demanded divided by the percentage change in price. An elasticity less than one in absolute value shows that demand is inelastic – that is, people are relatively unresponsive to price changes, and the percent change in quantity demanded is less than the percent change in price. In this case, revenues (price times quantity sold) will increase as the price increases; additional revenues from people who continue to purchase the pass is greater than the loss in revenue from those who no longer purchase the pass. Conversely, an elasticity greater than one in absolute value shows that demand is elastic – that is, people are more responsive to price changes, and the percent change in quantity demanded is greater than the percent change in price. In this case, revenues will decrease as the price increases; additional revenues from people who continue to purchase the pass do not make up for the loss in revenue from those who no longer purchase the pass due to the higher price.

Using updated calibration factors based on current sales data, we estimate the projected number of pass-holders, price elasticity of demand, and pass revenue (in aggregate across all agencies) for both the unconditional and conditional estimates at various pass prices. These results are shown in Table 7. Based on the unconditional estimates, people are relatively unresponsive to small increases in the price of the pass from the current price of $80 up to about $95. Thus, we see an increase in pass revenue as the pass price increases from $80 up to $95. Beyond that, the estimates predict large decreases in the number of passes sold and therefore, a decrease in pass revenue. The conditional estimates tell a different story - people are relatively responsive to price increases, resulting in a loss in pass revenue as the pass price increases beyond $80. It should be noted that Aadland and Shogren (2006) put more confidence in the unconditional estimates compared to the conditional estimates. This is due to the fact that the econometric model used to generate the conditional estimates tended to do a better job of predicting willingness-to-pay for households on the low end of the willingness-to-pay distribution than on the high end. Because of the poorer fit at the high end, the model tends to incorrectly predict that households will not purchase the pass at high prices (resulting in larger elasticities at high pass prices). Given the difference in the two estimates, we also estimated an econometric model based on households' responses to the first CV question only (ignoring responses to the follow-up question), as the literature has found some evidence of internal inconsistency between responses to the first and second CV questions (Bateman et al., 2001; Cameron and Quiggin, 1994). The results of this model fell between the unconditional and conditional

estimates, but aligned more closely with the unconditional estimates. These results predict that demand is inelastic at price increases from $80 up to about $90 (with pass revenue of $26.6 million), but once the pass price hits around $95 and beyond, demand becomes elastic and pass revenues begin to drop.

**Table 7. Projected Number of Pass-holders, Price Elasticity of Demand, and Pass Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders |
| $60 | 561,233 | | 33.7 | 549,228 | | 33.0 |
| $65 | 403,684 | -3.37 | 26.2 | 509,998 | -0.86 | 33.1 |
| $70 | 399,840 | -0.12 | 28.0 | 451,152 | -1.50 | 31.6 |
| $75 | 391,843 | -0.28 | 29.4 | 353,075 | -3.04 | 26.5 |
| $80 | 333,460* | -2.23 | 26.7* | 333,460* | -0.83 | 26.7* |
| $85 | 320,559 | -0.62 | 27.2 | 274,614 | -2.82 | 23.3 |
| $90 | 310,986 | -0.51 | 28.0 | 235,384 | -2.43 | 21.2 |
| $95 | 308,664 | -0.13 | 29.3 | 215,768 | -1.50 | 20.5 |
| $100 | 279,888 | -1.77 | 28.0 | 196,153 | -1.73 | 19.6 |
| $105 | 273,065 | -0.49 | 28.7 | 176,538 | -2.00 | 18.5 |
| $110 | 206,735 | -5.10 | 22.7 | 156,922 | -2.33 | 17.3 |
| $115 | 189,974 | -1.78 | 21.8 | 137,307 | -2.75 | 15.8 |
| $120 | 189,507 | -0.06 | 22.7 | 137,307 | 0.00 | 16.5 |

*actual

NB: Shading indicates inelastic portions of the demand curve (estimated elasticity of demand less than 1.0 in absolute value).

Next we calculate projected gate revenues at various Interagency Annual Pass prices, following the approach taken by Aadland and Shogren (2006). Each household has a particular willingness-to-pay for the pass, and the most they should be willing to pay for the pass is the amount they expect to spend at the gate for all sites they plan to visit that year. They will purchase the pass if their willingness-to-pay is greater than or equal to the price of the pass. If their willingness-to-pay is less than the price of the pass,

they won't purchase the pass, but it is assumed that they will pay their exact willingness-to-pay in gate entrance fees at various recreation sites. For example, say the pass costs $80 but a household is only willing to pay $60 for it. Since their willingness-to-pay is less than the price of the pass, they will not purchase it, but may instead visit a park that charges a $20 entrance fee three times in one year, or alternatively, they may visit a site that charges a $10 entrance fee six times in one year, spending their exact $60 willingness-to-pay to access federal recreation sites. This approach assumes that households do not systematically over or underestimate the expected number of trips to federal recreation sites, and that the decision to purchase the pass is based solely on its economic value. Therefore, at a particular pass price, total gate revenue is calculated by summing willingness-to-pay for all households with willingness-to-pay less than the price of the pass, scaled to the relevant population. Table 8 shows projected pass revenue, gate revenue, and total revenue (pass revenue + gate revenue) at pass prices ranging from $60 to $120. These estimates are calibrated for hypothetical bias, and again, represent totals across all agencies participating in the pass program.

**Table 8. Projected Pass Revenue, Gate Revenue and Total Revenue (Pass+Gate) at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) |
| $60 | 33.7 | 181.1 | 214.7 | 33.0 | 213.8 | 246.8 |
| $65 | 26.2 | 191.5 | 217.8 | 33.1 | 216.3 | 249.5 |
| $70 | 28.0 | 191.8 | 219.8 | 31.6 | 220.2 | 251.8 |
| $75 | 29.4 | 192.4 | 221.8 | 26.5 | 227.2 | 253.7 |
| $80 | 26.7* | 194.2 | 220.8 | 26.7* | 228.8 | 255.4 |
| $85 | 27.2 | 195.0 | 222.3 | 23.3 | 233.6 | 256.9 |
| $90 | 28.0 | 195.9 | 223.9 | 21.2 | 236.9 | 258.1 |
| $95 | 29.3 | 197.7 | 227.0 | 20.5 | 238.7 | 259.2 |
| $100 | 28.0 | 199.4 | 227.4 | 19.6 | 240.6 | 260.2 |
| $105 | 28.7 | 199.9 | 228.5 | 18.5 | 242.6 | 261.1 |
| $110 | 22.7 | 208.2 | 230.9 | 17.3 | 244.7 | 262.0 |
| $115 | 21.8 | 209.0 | 230.9 | 15.8 | 246.8 | 262.6 |
| $120 | 22.7 | 209.0 | 231.8 | 16.5 | 246.8 | 263.3 |

*actual

The unconditional estimates show pass revenue increasing as the price of the pass increases from the current price of $80 up to about $95, and gate revenues and total revenues continue to increase as the price of the pass increases. The conditional estimates show pass revenue decreasing at prices beyond $80, but gate revenues and total revenues steadily increase as the price of the pass increases.

Finally, we calculate foregone revenue, again following the approach taken by Aadland and Shogren (2006). Foregone revenue is simply total revenues in the absence of the pass program minus total revenues with the pass program. Setting the price of the pass in a way that doesn't sacrifice substantial revenues (in aggregate across all agencies) would require foregone revenue to approach zero. This would imply that the program is revenue neutral. Total revenues with the pass program are shown above in Table 8.

**Table 9. Projected Foregone Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | Conditional Estimates |
|---|---|---|
| Pass Price | Foregone Revenue (millions of dollars) | Foregone Revenue (millions of dollars) |
| $60 | 27.1 | 21.3 |
| $65 | 25.4 | 18.6 |
| $70 | 23.6 | 16.3 |
| $75 | 21.4 | 14.3 |
| $80 | 18.8 | 12.6 |
| $85 | 17.9 | 11.1 |
| $90 | 16.6 | 10.0 |
| $95 | 16.4 | 8.9 |
| $100 | 13.6 | 7.8 |
| $105 | 12.1 | 6.9 |
| $110 | 10.1 | 6.1 |
| $115 | 9.9 | 5.4 |
| $120 | 7.9 | 4.7 |

To estimate total revenues in the absence of the pass program, we simply sum willingness-to-pay for every household in the sample, and scale it to the relevant population. This assumes that, if a household does not have the option to purchase the Interagency Annual Pass, they will simply spend their exact willingness-to-pay for the pass on gate entrance fees at federal recreation sites. Estimates of foregone revenue at various pass prices, also calibrated for hypothetical bias, are shown in Table 9. Under both the unconditional and conditional estimates, foregone revenue is predicted to continue to decrease as the price of the pass increases.

In summary, based on the analysis outlined in Aadland and Shogren (2006), which has been updated using recent sales data, increasing the price of the Interagency Annual Pass from the current price of $80 is expected to result in increased total revenues (and thus decreased foregone revenues) across all agencies participating in the pass program. Further, based on the unconditional estimates, small increases in the price of the Interagency Annual Pass are not expected to greatly reduce demand, meaning revenue from the sale of the pass may also increase if it's sold at a slightly higher price.

This analysis has assumed that people's motivation for buying the pass is based on economic considerations alone - that is, they will buy the pass if it reduces their expected costs associated with visitation to federal recreation sites. This is a realistic assumption given that the majority of survey respondents agreed that "the price of the pass compared to the cost of entrance fees" is an important reason to purchase the pass. This was also the primary motivation reported by the Biometrics (2016) survey of central-sales pass purchasers. However, if people are motivated to purchase the pass for other reasons, such as the convenience of not having to make separate entrance fee payments at each site or because they view the pass as a means to maintain and enhance federal lands and facilities, then foregone revenues would be lower at every price point.

Lastly, it is important to note that although the results from Aadland and Shogren (2006) have been updated using current sales data, they are still based on responses to a survey that was conducted more than a decade ago. People now have ten years of experience using the Interagency Annual Pass. A new study would be required to determine whether this experience, or any other factors, have impacted people's motivations for buying the pass or caused potential pass purchasers to be more or less responsive to price changes than indicated by the results presented here.

## Recommendations for Future Study

There are various reasons that program managers may want to consider conducting a new study of the Interagency Annual Pass. The most recent economic analysis used to assist in pricing of the pass was completed more than ten years ago, and many changes have occurred since then. The Annual Pass is no longer a hypothetical good, and the public now has a decade of experience and familiarity with it. The pass itself has evolved over time. For instance, it provides access to additional federal recreation sites that have been designated since 2006, and recreation sites managed by the U.S. Army Corps of Engineers are now included in the program. In addition, population, per capita income, and prices have increased in the last ten years, and many federal recreation sites now charge higher entrance/standard amenity fees. Any of these factors have the potential to affect people's motivations for purchasing the pass and the amount that they are willing to pay for it.

It may also be worth developing data on prices of alternatives, such as entrance fees and pass prices for State parks, or Parks Canada. For example, California's State parks pass is now priced at $195. A total of 36 States appear to offer an annual pass, and a further 7 States have no charge for visiting State parks.[18] It may also be worth collecting data on entrance fees at other types of substitute activities (e.g., amusement parks). A broader study could look at how entrance fees figure into travel planning; this would inform estimates of sensitivity to price changes. An area offering the potential for general improvements for managing recreation lands is improving visitation estimates. For example, NPS Visitor Use Statistics and the USFS National Visitor Use Model offer rigorous approaches that could be adopted at other agencies.

For a better understanding of the mechanics of revenue neutrality, it could be useful to study the effect of recreation price changes on site conditions, both directly (via maintenance budgets) and indirectly (via visitation levels). A review of the interaction between prices, visitation, and site conditions (e.g., resource conditions, crowding, required maintenance, etc.) at federal and State sites could prove informative as FLREA agencies review their pricing policies. Walls (2016) suggests that seasonal prices are an effective way to address crowding and to deal with maintenance requirements that increase with visitation.

If it is determined that a comprehensive study of the Interagency Annual Pass is warranted, a new pricing analysis could provide updated and more accurate information on: 1. The expected number of Interagency Passes sold and associated revenues at various prices (i.e., the demand curve); 2. The sensitivity of passes demanded to price changes (i.e., the price elasticity of demand); 3. The price of the pass required to

[18] http://usparks.about.com/od/usstateparks/tp/State-Park-Passes.htm

maintain revenue neutrality, if that is determined to be a goal. A survey-based economic valuation method similar to the one outlined in Aadland and Shogren (2006) would most likely be used to obtain this information. It would be worthwhile to survey a random sample of U.S. households, as well as households known to have purchased the Interagency Annual Pass.

In addition to the economic analysis, a detailed evaluation of people's motivations for buying the pass could be undertaken to complement the findings in the survey of centrally sold pass purchasers (Bioeconomics, 2016).[19] These motivations can affect total revenues as well as foregone revenues at various pass prices, as shown in Aadland and Shogren (2006). Additional survey questions similar to those used in the central-sales survey could be included to determine other information that would be useful to the interagency pass program, such as people's satisfaction with the current Interagency Pass and the effectiveness of marketing techniques. A survey of the American public such as this could also potentially provide information about other high-priority issues for the agencies. Detailed discussions with program managers would be necessary to determine the specific goals of such a study. A comprehensive study would most likely require survey development, focus groups, and OMB approval, and would take approximately 18-24 months to complete. Additional funding would be required for a contractor to assist DOI/NPS with this effort.

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[19] The Bioeconomics survey covered a variety of topics, including 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-03-02T12:47:24-05:00
**Importance:** Normal
**Subject:** EKIP Redemption Report
**Received:** 2017-03-02T12:48:00-05:00
EKIP Redemption Data 9-1-2016 - 2-28-2017.xlsx

Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong. Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

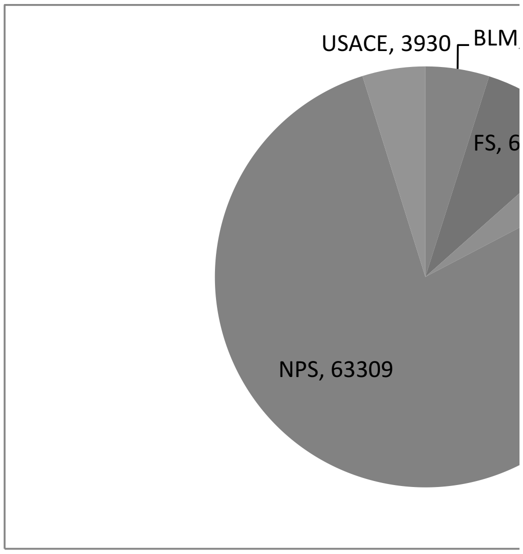
# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 2/28/2017**

**FOR INTERNAL USE ONLY**

| | |
|---|---|
| **Grand Total** | **81,326** |
| **BLM** | **3,984** |
| Red Rock Canyon National Conservation Area BLM | 840 |
| California BLM Office | 717 |
| Eagle Lake BLM Field Office | 351 |
| National Historic Trails Interpretive Center | 258 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| Red Rock Canyon National Conservation Area - BLM | 203 |
| Gunnison Gorge National Conservation Area | 194 |
| Klamath Falls Resource Area | 189 |
| BLM Eastern States Office | 163 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Redding BLM Field Office | 111 |
| Alturas BLM Field Office | 99 |
| Nevada BLM Office | 83 |
| Coos Bay BLM District Office | 69 |
| Rio Puerco BLM Field Office | 59 |
| BLM Medford Office | 54 |
| Colorado BLM Office | 54 |
| Miles City BLM Office | 13 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Yaquina Head Oustanding Natural Area | 11 |
| Spokane BLM Office | 9 |
| Utah BLM Office | 4 |
| Royal Gorge BLM Field Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Arizona BLM State Office | 2 |
| Eugene District BLM Office | 1 |
| Rock Springs Field Office - BLM | 1 |
| Wyoming BLM Office | 1 |
| **FS** | **6,946** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Stanislaus NF - Mi-Wok District | 500 |
| Lincoln NF - Sacramento District | 397 |
| Rogue River - Siskiyou NF - Main Office | 368 |
| US Forest Service Region 9 | 331 |
| Umpqua NF - Main Office | 330 |

**4.9%**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BLM
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NPS, 63309

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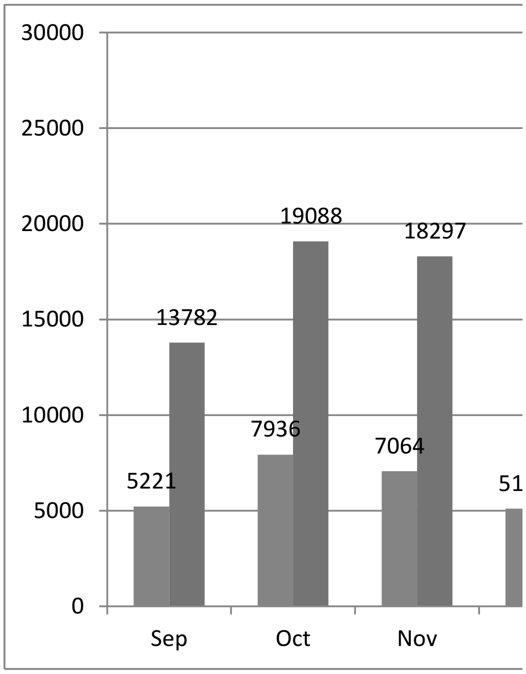
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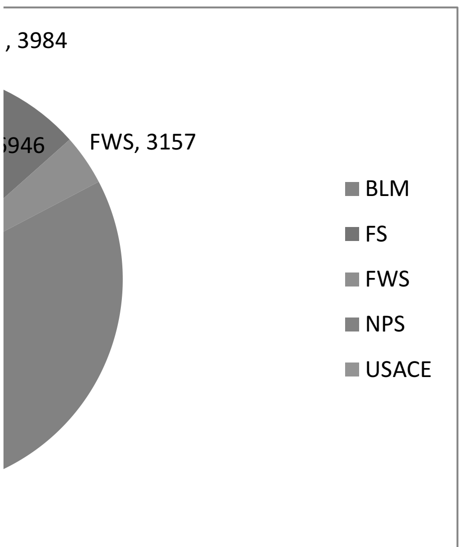


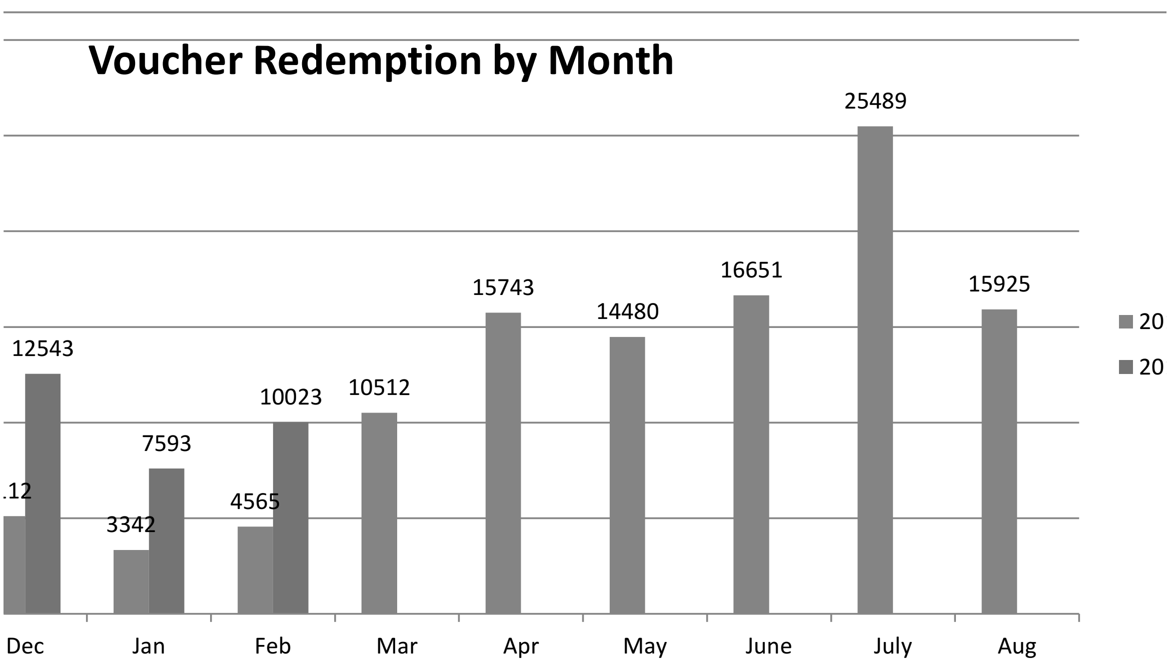

15/2016

16/2017

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|---|---|
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Land Between the Lakes | 279 |
| Fremont-Winema NF - Main Office | 244 |
| US Forest Service Regional Office | 238 |
| Chugach National Forest | 184 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 151 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Ocala NF - Lake George District | 110 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Bighorn NF - Powder River District | 108 |
| Caribou-Targhee NF - Dubois District | 107 |
| Umpqua NF - Diamond Lake Visitor Center | 106 |
| Olympic NF - Main Office | 91 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 80 |
| Carson NF - Main Office | 71 |
| Malheur NF - Emigrant Creek District | 67 |
| Lewis & Clark NF - Main Office | 64 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Coconino NF - Red Rock Visitor's Center | 57 |
| Clearwater NF - Main Office | 55 |
| Mt Hood NF - Zigzag District | 53 |
| Umpqua NF - North Umpqua District | 51 |
| Colville NF - Republic District | 40 |
| Coconino NF - Red Rock District | 36 |
| Pike & San Isabel NF - South Platte District | 35 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Bighorn NF - Main Office | 32 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 29 |
| Black Hills NF - Mystic District | 28 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| Shasta-Trinity NF - Main Office | 27 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 24 |
| Humboldt-Toiyabe NF - Bridgeport District | 24 |
| Tonto NF - Main Office | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |
| Coronado NF - Main Office | 21 |
| Tonto NF - Mesa District | 21 |
| Washington & Jefferson NF - Lee District | 20 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 19 |

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|---|---|
| Prescott NF - Bradshaw District | 18 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Fishlake NF - Fillmore District | 17 |
| Sequoia NF - Main Office | 17 |
| Carson NF - El Rito Station | 17 |
| Humboldt-Toiyabe NF - Main Office | 15 |
| Kaibab NF - North Kaibab District | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Manti-La Sal NF - Sanpete District | 13 |
| Sawtooth NF - Fairfield District | 13 |
| Caribou-Targhee NF - Westside District | 12 |
| Tonto NF - Cave Creek District | 12 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 11 |
| Santa Fe NF - Main Office | 11 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 11 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Idaho Panhandle NF - Coeur d'Alene River District | 10 |
| Sawtooth NF - Main Office | 9 |
| Black Hills NF - Main Office | 9 |
| Six Rivers NF - Mad River District | 8 |
| Fishlake NF - Main Office | 8 |
| Manti-La Sal NF - Main Office | 8 |
| Kaibab NF - Williams District | 7 |
| Gifford Pinchot NF - Main Office | 7 |
| Fishlake NF - Fremont River District | 6 |
| Coconino NF - Mogollon Rim District | 6 |
| Sawtooth NF - Minidoka District | 6 |
| Flathead NF - Tally Lake District | 6 |
| White River NF - Dillon District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| Bighorn NF - Medicine Wheel/Paintrock District | 5 |
| Coconino NF - Main Office | 5 |
| Kaibab NF - Main Office | 5 |
| Willamette NF - McKenzie River District | 4 |
| Colville NF - Newport District | 4 |
| Uinta-Wasatch-Cache NF - Evanston District | 4 |
| Olympic NF - Pacific District | 4 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Prescott NF - Chino District | 4 |
| Malheur NF - Main Office | 3 |
| Okanogan-Wenatchee NF - Cle Elum District | 3 |
| Crooked River National Grasland | 3 |
| Klamath NF - Main Office | 3 |

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| | |
|---|---|
| Inyo NF - Mammoth Lakes Center | 3 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Angeles NF - Main Office | 3 |
| Payette NF - McCall District | 3 |
| Mt Hood NF - Clackamas River District | 3 |
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| San Bernardino NF - Main Office | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Okanogan-Wenatchee NF - Main Office | 3 |
| Green Mountain NF - Middlebury Station | 2 |
| Idaho Panhandle NF - Main Office | 2 |
| Black Hills NF - Bearlodge District | 2 |
| Fishlake NF - Beaver District | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| Coronado NF - Douglas District | 2 |
| Rogue River - Siskiyou NF - Gold Beach District | 2 |
| Cleveland NF - Trabuco District | 2 |
| San Bernardino NF - Front Country District - San Gorgonio Ranger Station | 2 |
| Willamette NF - Detroit District | 2 |
| San Juan NF - Dolores District | 2 |
| Uinta-Wasatch-Cache NF - Logan District | 2 |
| Nez Perce NF - Main Office | 2 |
| Beaverhead-Deerlodge NF - Main Office | 2 |
| Helena NF - Helena District | 2 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| Helena NF - Lincoln District | 2 |
| Siuslaw NF - Main Office | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Grey Towers National Historic Site | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Umatilla NF - Walla Walla District | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Colville NF - Three Rivers District | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Kaibab NF - Tusayan District | 1 |
| Tahoe NF - Main Office | 1 |
| Payette NF - New Meadows District | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| Shasta-Trinity NF - Weaverville Station | 1 |
| Umpqua NF - Cottage Grove District | 1 |

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| | |
|---|---|
| Sawtooth NF - Stanley District | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |
| Green Mountain NF - Main Office | 1 |
| Los Padres NF - Main Office | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Sierra NF - Main Office | 1 |
| Ottawa NF - Visitor Center | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| San Juan Public Lands Center - FS | 1 |
| Routt NF - Parks Walden District | 1 |
| Sawtooth NF - Ketchum District | 1 |
| Rogue River - Siskiyou NF - Wild Rivers District | 1 |
| Mendocino NF - Main Office | 1 |
| Umatilla NF - Main Office | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| White Mountain NF - Saco District | 1 |
| Arapahoe & Roosevelt NF - Sulphur District | 1 |
| Six Rivers NF - Orleans District | 1 |
| Coronado NF - Santa Catalina District | 1 |
| San Juan NF - Pagosa District | 1 |
| Gallatin NF - Hebgen Lake District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Croatan NF - Main Office | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Siuslaw NF - Waldport Office | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Sam Houston NF | 1 |
| **FWS** | **3,157** |
| J.N. "Ding" Darling National Wildlife Refuge | 1,494 |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 350 |
| Sam D. Hamilton Noxubee NWR | 258 |
| Arthur R. Marshall Loxahatchee NWR | 231 |
| St. Marks National Wildlife Refuge | 125 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| Back Bay NWR | 91 |
| Merritt Island National Wildlife Refuge | 83 |
| DeSoto National Wildlife Refuge | 67 |
| Bombay Hook National Wildlife Refuge | 65 |
| Nisqually NWR | 58 |
| Sacramento NWR | 36 |
| Two Rivers National Wildlife Refuge | 25 |

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**3.9%**

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| | |
|---|---|
| Fish and Wildlife Service Regional Office | 18 |
| Chincoteague NWR | 18 |
| National Elk Refuge | 10 |
| Don Edwards San Francisco Bay NWR | 9 |
| Ottawa National Wildlife Refuge | 3 |
| Parker River National Wildlife Refuge | 3 |
| Bosque del Apache NWR | 1 |
| Ridgefield NWRC | 1 |
| **NPS** | **63,309** |
| San Juan National Historic Site | 5,163 |
| Assateague Island National Seashore | 4,757 |
| Colonial National Historical Park | 3,265 |
| Yosemite National Park | 2,512 |
| Chamizal National Memorial | 2,132 |
| Chesapeake & Ohio Canal NHP | 2,058 |
| Fort McHenry National Monument | 2,056 |
| Hopewell Culture National Historical Park | 2,046 |
| Mount Rainier National Park | 1,922 |
| Indiana Dunes National Lakeshore | 1,896 |
| Lake Mead National Recreation Area | 1,752 |
| Cuyahoga Valley National Park | 1,407 |
| Grand Canyon National Park | 1,278 |
| Joshua Tree National Park | 1,253 |
| Acadia National Park | 1,133 |
| Richmond National Battlefield Park | 1,081 |
| Garfield National Historic Site | 1,065 |
| Rocky Mountain National Park | 1,063 |
| Zion National Park | 1,049 |
| Channel Islands National Park | 1,044 |
| Great Falls Park | 936 |
| Walnut Canyon National Monument | 921 |
| Petroglyph National Monument | 878 |
| Yellowstone National Park | 828 |
| Arches National Park | 796 |
| Cedar Breaks National Monument | 743 |
| Catoctin Mountain Park | 688 |
| Harpers Ferry National Historical Park | 666 |
| Death Valley National Park | 665 |
| Colorado National Monument | 646 |
| Sequoia & Kings Canyon National Park | 550 |
| San Francisco Maritime National Historical Park | 526 |
| Sleeping Bear Dunes National Lakeshore | 508 |
| Petrified Forest National Park | 505 |
| Pinnacles National Monument | 495 |
| Organ Pipe Cactus National Monument | 466 |

**77.8%**

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| | |
|---|---|
| Lewis & Clark National Historical Park | 446 |
| Montezuma Castle National Monument | 430 |
| Blue Ridge Parkway (Campgrounds) | 412 |
| Olympic National Park | 389 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 378 |
| Pu'uhonua O Honaunau | 370 |
| Bryce Canyon National Park | 352 |
| Capulin Volcano National Monument | 335 |
| Everglades National Park | 330 |
| Big South Fork National River & Recreation Area | 313 |
| Wright Brothers National Memorial | 294 |
| Big Thicket National Preserve | 281 |
| Casa Grande Ruins National Monument | 276 |
| Tumacacori National Historical Park | 275 |
| Cabrillo National Monument | 264 |
| Gila Cliff Dwellings National Monument | 257 |
| Hawaii Volcanoes National Park | 231 |
| Shenandoah National Park - Thornton Gap Entrance | 227 |
| Dinosaur National Monument (Passes only sold at UT location)) | 225 |
| Castillo de San Marcos National Monument | 222 |
| Grand Teton National Park | 219 |
| Florissant Fossil Beds National Monument | 210 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Lowell National Historical Park | 207 |
| Tonto National Monument | 195 |
| Hot Springs National Park | 192 |
| Badlands National Park | 186 |
| Shenandoah National Park - Front Royal Entrance | 181 |
| Fort Washington Park | 178 |
| Crater Lake National Park | 175 |
| Glacier National Park | 165 |
| Shenandoah National Park - Swift Run Entrance | 165 |
| Fossil Butte National Monument | 161 |
| Carlsbad Caverns National Park | 155 |
| Lava Beds National Monument | 134 |
| Delaware Water Gap National Rec Area | 133 |
| Mesa Verde National Park | 131 |
| Little Rock Central High School NHS | 124 |
| Saguaro National Park | 121 |
| Jewel Cave National Monument | 120 |
| Lassen Volcanic National Park | 113 |
| Bighorn Canyon National Recreation Area | 112 |
| Fort Vancouver National Historic Site | 109 |
| Canyonlands National Park | 100 |
| Aztec Ruins National Monument | 100 |

91 entered by BISC on 12/7

241 from SAAN including 120 from 2015/2016 exchanges

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| | |
|---|---|
| Greenbelt Park | 98 |
| Big Bend National Park | 97 |
| Chickamauga & Chattanooga National Military Park | 89 |
| Haleakala National Park | 88 |
| Saint Gaudens National Historic Site | 87 |
| Antietam National Battlefield | 81 |
| Great Sand Dunes National Park | 79 |
| Craters of the Moon National Monument | 76 |
| Prince William Forest Park | 74 |
| Sunset Crater Volcano National Monument | 71 |
| Mammoth Cave National Park | 69 |
| Obed Wild and Scenic River | 68 |
| Shenandoah National Park - Rockfish Entrance | 66 |
| White Sands National Monument | 62 |
| Gulf Islands National Seashore | 62 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| Klondike Gold Rush National Historical Park | 60 |
| William Howard Taft National Historical Site | 60 |
| Edison National Historical Park | 58 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Golden Spike National Historic Site | 42 |
| Devils Tower National Monument | 41 |
| Steamtown National Historic Site | 41 |
| Wind Cave National Park | 40 |
| Weir Farm National Historic Site | 37 |
| Timpanogos Cave National Monument | 36 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Canaveral National Seashore | 34 |
| Bandalier National Monument | 32 |
| Pictured Rocks National Seashore | 31 |
| Fort Union National Monument | 30 |
| Capitol Reef National Park | 29 |
| Padre Island National Seashore | 29 |
| Vicksburg National Military Park | 26 |
| Mount Rushmore National Memorial | 24 |
| Whiskeytown National Recreation Area | 20 |
| Theodore Roosevelt National Park - South Unit | 20 |
| Little Bighorn Battlefield National Monument | 20 |
| Saratoga National Historical Park | 19 |
| Scotts Bluff National Monument | 19 |
| Pipestone National Monument | 19 |
| Denali National Park & Preserve | 16 |
| Fort Moultrie National Monument | 16 |
| Pipe Spring National Monument | 15 |

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| | |
|---|---|
| Lincoln Boyhood National Memorial | 15 |
| Fort Davis National Historic Site | 14 |
| Wilson's Creek National Battlefield | 13 |
| Harry S Truman National Historic Site | 12 |
| Great Smoky Mountains NP - Sugarland VC | 12 |
| Great Smoky Mountains NP - Oconaluftee Visitor's Center | 10 |
| Tuzigoot National Monument | 10 |
| Chaco Culture National Historical Park | 9 |
| Great Basin National Park | 8 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 8 |
| Ulysses S Grant National Historic Site | 7 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| Wupatki National Monument | 7 |
| Chickasaw National Recreation Area | 6 |
| Natural Bridges National Monument | 5 |
| Herbert Hoover National Historical Site | 5 |
| Fort Necessity National Battlefield | 4 |
| Johnstown Flood National Memorial | 4 |
| Carl Sandburg Home National Historic Site | 3 |
| Great Smoky Mountains NP - Smokemont Campground | 3 |
| Great Smoky Mountain NP - Cades Cove Campground | 3 |
| Valles Caldera National Preserve | 3 |
| Isle Royale National Park | 2 |
| Mississippi National River & Recreation Area | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| National Historic Oregon Trail Interpretive Center | 2 |
| Homestead National Monument of America | 1 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| **USACE** | **3,930** |
| Philpott Lake | 1,349 |
| Mississippi River Project | 738 |
| Proctor lake | 261 |
| Lake Shelbyville | 251 |
| Wappapello Lake | 180 |
| Carters | 175 |
| Sandy Lake Recreation Area | 173 |
| Gull Lake Recreation Area | 154 |
| Woodruff-Seminole | 150 |
| John H. Kerr Dam and Reservoir | 112 |
| Greers Ferry Lake | 60 |
| Englebright Lake | 59 |
| Falls Lake | 54 |
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Allatoona | 33 |

**4.8%**

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| | |
|---|---|
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Table Rock Lake | 4 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| West Hill Dam | 3 |
| North Hartland Lake | 2 |
| Tioga-Hammond Lakes Project | 1 |
| Cowanesque Lake Project | 1 |
| Success Lake | 1 |
| Abiquiu Lake | 1 |
| Hensley Lake | 1 |
| Raystown Lake Project | 1 |
| Bay Model Visitor Center | 1 |
| **(blank)** | |
| (blank) | |
| **Grand Total** | **81,326** |

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-03-13T09:34:25-04:00
**Importance:** Normal
**Subject:** Pass Pricing Study Report - FINAL Version
**Received:** 2017-03-13T09:35:01-04:00
Pricing of the Interagency Annual Pass - Final 2017-03-10.pdf

Hello everyone,
Attached is the final Pass Pricing Study Report. We can discuss distribution of the report on our call tomorrow. Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

# Pricing of the Interagency Annual Pass: A Review of Existing Data and Analyses

Leslie Richardson[1] and Christian Crowley[2]

[1]Economist, National Park Service, Social Science Program, leslie_a_richardson@nps.gov, 970-267-7313

[2]Economist, Department of the Interior, Office of Policy Analysis, christian_crowley@ios.doi.gov, 202-208-3799

## Contents

## Executive Summary

The Interagency Annual Pass, which provides access to more than 2,000 federal recreation sites that charge an entrance fee or other day use fee, has been available at a price of $80 since 2007. The goal of this effort was to evaluate various sources of existing data and analyses to help inform potential changes in the price of the Annual Pass. Specifically, we looked at recent reviews and audits, agency revenues and pass sales, entrance and other site access fees, and a 2006 pricing analysis of the Interagency Annual Pass, which was updated in this report using current pass sales data.

Key findings indicate that a modest increase in the price of the Interagency Annual Pass may be warranted for the following reasons:

- If the Interagency Annual Pass were adjusted for inflation, the pass that cost $80 in 2007 would cost about $93 in 2016. The price of the pass has never been adjusted for inflation, meaning in real dollars, the pass is more than 10% cheaper than it was when it was introduced.
- As noted in the University of Wyoming's 2006 Interagency Annual Pass pricing study, whatever base price is chosen for the pass could be adjusted upward in advance to account for future increases in entrance fees. In reality, entrance fees at NPS sites increased by more than 40% once the moratorium on fee increases was lifted in 2014 (equivalent to a 3 to 5 percent increase per year since 2007), whereas the Interagency Annual Pass has remained at $80 since 2007.
- Based on an evaluation of recreation fee and revenue changes over time, it appears that visitation to NPS sites is relatively unresponsive to increases in entrance and other site access fees. A similar finding can be gleaned from our update of the University of Wyoming's 2006 pricing analysis. As a result, increasing the price of the Interagency Annual Pass up to $90 or even $95 is not expected to greatly reduce demand or pass revenues, and it should serve to increase total revenues and reduce 'foregone' revenues in aggregate across all agencies participating in the pass program.

Of course, numerous objectives have to be balanced when evaluating the price of the Interagency Annual Pass. For instance, a higher price is likely to increase total revenues, but may discourage visitation to federal lands relative to a lower pass price, especially if entrance fees also continue to increase. This raises questions of what represents a 'fair' pass price, in terms of maintaining affordable access to federal recreation sites. In addition, it was beyond the scope of this study to evaluate any indirect effects of increasing the price of the pass (such as reduced visitor crowding), or the distributional effects of pricing changes on individual agencies. Finally, this effort evaluated existing data and analyses only. A new

comprehensive study of the Interagency Annual Pass could be undertaken to determine people's satisfaction with the current pass, assess their motivations for buying the pass, and conduct a more accurate and updated pricing analysis.

## Introduction

In 2007, the Interagency Annual Pass, also referred to as the "America the Beautiful – the National Parks and Federal Recreational Lands Pass," was made available to the public, replacing the Golden Eagle and National Parks Passes. The pass covers entrance and standard amenity fees at federal recreation sites managed by the National Park Service, Fish and Wildlife Service, the Forest Service, Bureau of Land Management, Bureau of Reclamation, and the U.S. Army Corps of Engineers. In selecting a price for the pass, the goal was to charge a price that made sense in economic terms, was defensible and understandable to decision makers and the public, and would not cause total revenues across all agencies to be less than total revenues in the absence of the pass program. In addition, the price should take into account people's willingness-to-pay for the convenience of using the pass and any altruistic motives they may have. An economic analysis conducted by the University of Wyoming (described in greater detail below) was used to help select a price for the Interagency Annual Pass. Ultimately, the price was set at $80 in 2007 and has not changed since.

Now that the pass has been available for ten years, various sources of existing data can be evaluated and updated to help inform potential changes in the price of the pass. For instance, national park visitors typically have three ways to access sites that charge a day use fee: use the Interagency Annual Pass, pay the daily entrance fee, or use an annual pass that covers entrance to that particular park only. Although the price of the Interagency Annual Pass has not changed, looking at changes in the price of the other two 'substitutes' can provide some insight into how responsive visitors are to price changes. In addition, the University of Wyoming's 2006 pricing analysis can be updated using recent sales data for the Interagency Annual Pass. The overall goal of this effort is to provide information from multiple sources to help policymakers evaluate alternative prices for the pass.

The remainder of this report is outlined as follows. First, background information is provided, including the history of fees under FLREA, history of the Interagency Pass, a summary of the University of Wyoming's 2006 pricing analysis, as well as a summary of recent reports on NPS recreation revenues. Next, an analysis of agency-level revenue, visitation, and entrance fee data is provided. An update to the

University of Wyoming's 2006 pricing analysis is then presented, followed by recommendations for future study.

# Background

Federal recreation sites in the United States annually host hundreds of millions of visitors, including for 2015:

- 370 million visits to Army Corps of Engineers areas;[1]
- 307 million visits to National Park Service sites;[2]
- 188 million estimated visits to National Forest System sites;[3]
- 62 million estimated visits to Bureau of Land Management sites;[4]
- 48 million estimated visits to National Wildlife Refuges;[5] and
- 28 million estimated visits to Reclamation sites.[6]

Recreation facilities and opportunities at many of these sites are funded in part by visitors, through revenue collected under the Federal Lands Recreation Enhancement Act (FLREA). FLREA revenue, in the form of on-site fees and pass sales, is an important funding source for federal lands management, along with Congressional appropriations, donations, rents, commercial use fees, etc.

## History of Fees under FLREA

The National Recreation Fee Demonstration Program was created in 1996 as a three-year pilot program. This was followed by FLREA in 2004. Under FLREA federal land management agencies are authorized to collect fees from visitors, and to use those fees to develop and maintain public recreation sites. Participating agencies include the Department of the Interior's (DOI's) Bureau of Land Management (BLM), Bureau of Reclamation (Reclamation), National Park Service (NPS), and U.S. Fish and Wildlife Service (FWS); and the U.S. Department of Agriculture's (USDA's) Forest Service (USFS). The U.S.

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[1] Annual average, from http://www.usace.army.mil/Missions/Civil-Works/Recreation/
[2] NPS Annual Visitation Summary Report for 2015 https://irma.nps.gov/Stats/SSRSReports/National%20Reports/Annual%20Visitation%20Summary%20Report%20(1979%20-%20Last%20Calendar%20Year)
[3] https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf
[4] BLM Public Land Statistics, FY 2015, Table 4-1. https://www.blm.gov/public_land_statistics/pls15/pls2015.pdf
[5] DOI data.
[6] DOI data

Army Corps of Engineers (USACE) was authorized to join the FLREA pass program in the 2014 Water Resources Reform and Development Act.[7]

FLREA authorizes the agencies to charge several types of fees:

- NPS and FWS charge *entrance fees* at sites like National Parks and Wildlife Refuges;
- BLM, USFS, and Reclamation charge *standard amenity recreation fees* at sites like picnic areas and interpretive sites;
- Agencies collect *expanded amenity recreation fees* for enhanced services such as a cabin rental, campgrounds, and boat launch facilities; and
- *Special Recreation Permits* for activities such as off-highway vehicle use, guiding, and events.

In deciding whether to establish or change fees at federally managed sites, the agencies engage with the public and stakeholders to ensure that the different perspectives are considered and that the fees are appropriate. Fees are currently charged at about 45% of NPS sites, 32% of USFS sites,[8] 10% of BLM sites, 7% of FWS refuges, and a single Reclamation site. FLREA fee revenue has increased steadily from $196 million in Fiscal Year (FY) 2005 to $278 million in FY 2014 (DOI and USDA, 2015).

## NPS Entrance Fees Study (2001)

McKinsey & Co (2001) completed a study of NPS entrance fees finding that prices were not standardized across the nation. The authors recommended developing a national model to determine prices. In 2006, NPS implemented a model updating prices for entrance fees (per-person, per-vehicle, and per-motorcycle) and single-park annual passes. NPS sites were divided into four groups, based on type of site and visitation levels:

- Group 4 includes the nine most-visited parks (Bryce, Glacier, Grand Canyon, Grand Teton, Rocky Mountain, Sequoia-Kings, Yellowstone, Yosemite, Zion);
- Group 3 includes all other National Parks;
- Group 2 includes the more visited non-Park unit-types (e.g., Seashores, Monuments);
- Group 1 includes the less visited non-Park unit-types (e.g. National Battlefields, Parkways)

[7] Since the enactment of FLREA, interagency passes have been accepted at certain sites managed by the U.S. Army Corps of Engineers (USACE) and Tennessee Valley Authority.
[8] USFS manages wilderness areas; 155 national forests; 22 national grasslands; 20 national recreation areas; 9 national scenic areas; and 7 national monuments, volcanic monuments, and national preserves (CRS, 2014; USFS, 2016b). Any of these units may contain a number of "sites" as defined by USFS, including a variety of recreation facilities, including hiking trails, campgrounds, alpine ski areas, picnic areas, boating sites, and swimming areas.

The 2006 model was initially implemented at 34 NPS units. In 2008 the National economy entered a recession, and NPS implemented a moratorium on increasing fees. In 2014, NPS lifted the moratorium and started applying fee increases using the updated pricing structure shown in Table 1. Proposed fee changes at an NPS site are subject to public review and comment through the "civic engagement" process. Proposed fees are reviewed by the Executive Committee and must be approved by the NPS National Leadership Council (NLC).

**Table 1. National Park Service Target Entrance Fees Based on Pricing Model (2014 Update)**

| Group | Site Types | Single-Park Annual Pass | Per Vehicle | Per Person | Motor-cycle |
|---|---|---|---|---|---|
| 1 | National Historic Sites, National Military Parks, National Battlefield Parks, National Memorials/Shrines, National Preserves, and Parkways | $30 | $15 | $7 | $10 |
| 2 | National Seashores, National Recreation Areas, National Monuments, National Lakeshores, and National Historic Parks | $40 | $20 | $10 | $15 |
| 3 | National Parks (most of the parks) | $50 | $25 | $12 | $20 |
| 4 | National Parks (certain parks, e.g., Grand Canyon) | $60 | $30 | $15 | $25 |
| | Increase over 2006 Fees | $10 | $5 | $2,$3 | $5 |
| | Equivalent annual % increase | 2%-5% | 2%-5% | 2%-5% | 3%-9% |

Sources: DOI and USDA (2015); GAO (2015)

## History of the Interagency Pass under FLREA

Prior to FLREA, various federal recreation sites accepted a variety of passes, including the Golden Eagle Passport, Golden Age Passport, Golden Access Passports, and the National Parks Pass. FLREA authorized a new interagency pass family called the "America the Beautiful - National Parks and Federal Recreational Lands Passes." Passes are sold at participating recreation sites, over the phone or online at websites like store.usgs.gov (so-called *central sales*), at third-party vendors (e.g., outdoors outfitters), and at certain agency offices. The agencies currently offer a variety of interagency passes accepted at FLREA sites around the country:

- An $80 Annual Pass;

- A $10 lifetime Senior Pass for those 62 and older;[9]
- A free Every Kid in a Park Pass for 4th graders;
- A free Access Pass for those with permanent disabilities;
- A free Annual Military Pass for members of the military and their families; and
- A free Volunteer Pass for those who volunteer 250 hours on public lands.

The agencies also have occasional fee-free days for the general public.

FLREA requires the agencies to report to Congress every three years on implementation of the recreation fee program. The 2015 Triennial Report shows that pass sales have continued to increase, up to nearly one million passes annually. As shown in Table 2, for FY 2012 through FY 2014 over 80 percent of sales were made at NPS sites, with a further 8 or 9 percent of the total sold at USFS sites, and the remaining 10 or 11 percent sold at sites managed by other agencies. Of the total passes sold, about two-thirds are for the $10 Senior Pass, and one-third are for the $80 Annual Pass.

**Table 2. Proportion of Interagency Passes Sold, by Agency and Pass Type**

| | FY 2012 | | FY 2013 | | FY 2014 | |
|---|---|---|---|---|---|---|
| NPS pass sales | 763,124 | 81% | 792,062 | 82% | 798,683 | 80% |
| USFS pass sales | 84,093 | 9% | 80,298 | 8% | 81,007 | 8% |
| Other Agency pass sales | 92,158 | 10% | 98,873 | 10% | 113,341 | 11% |
| Pass Types (All Agencies) | | | | | | |
| Annual Passes | 314,835 | 34% | 329,530 | 34% | 356,016 | 36% |
| Senior Passes | 624,540 | 66% | 641,703 | 66% | 637,015 | 64% |
| Total Passes | 939,375 | 100% | 971,233 | 100% | 993,031 | 100% |

Source: DOI and USDA (2015)

There was a dramatic increase in pass sales in FY 2015, leading up to the 2016 NPS Centennial. In FY 2015, NPS sites saw a 33 percent increase in the level of Annual Passes sold, compared to FY 2014. USFS sites saw a similar increase in Senior Passes sold over the same period (though only a 4 percent increase for Annual Passes), and FWS reported a 25% increase in all Interagency Passes sold. Central and

[9] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

third party sales saw an increase of over 45 percent (though these sources typically make up about 2 percent of pass sales).[10]

Pass-holders gain free entry to many recreational sites managed by federal agencies, however there is no centralized tracking system available to determine where and when the passes are used. In 2016 NPS published "The National Parks and Federal Recreational Lands Pass Survey," reporting the results of a survey of pass use among pass-holders who purchased an Annual Pass through central sales via the USGS website (rather than in person, at a recreation site). The repeat contact mail survey had a final response rate of 43.5%, with 772 completed surveys returned. The survey asked respondents to recall the last five times they had used their pass to access a recreation site.[11] Overall, approximately 85% of Annual Pass use was reported to be at NPS sites, and about 8% at USFS sites. Reclamation, BLM, and USFWS sites saw 2% or less of reported pass uses (Bioeconomics, 2016).

The price of the Interagency Annual Pass has remained at $80 since it was first introduced in 2007. Table 3 shows what the price of the pass would be each year if it kept pace with inflation.

**Table 3. Price of the Interagency Annual Pass if Adjusted for Inflation**

| | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| Pass Price | $83.07 | $82.78 | $84.13 | $86.79 | $88.59 | $89.88 | $91.34 | $91.45 | $92.60 |

## Summary of the University of Wyoming's 2006 Pricing Analysis

In 2005, the U.S. Department of Agriculture and the Department of the Interior issued a request for proposals to evaluate possible prices for the new Interagency Annual Pass. A project proposal submitted by the University of Wyoming, through its Wyoming Survey and Analysis Center, was selected to provide the requested assistance. The project consisted of five main tasks:

1. The production of a roadmap detailing the steps that would be taken to complete the remaining tasks;

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[10] Data from DOI and USDA, in personal communications.

[11] The survey also asked about 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

2. A benchmarking study used to compare existing federal recreation passes with state and Parks Canada passes;
3. An examination of theoretical and methodological issues in the economics of non-market valuation;
4. Focus groups; and
5. A national telephone survey.

The overall goal of the project was to provide information from multiple sources that could assist policymakers in determining a price for the new Interagency Annual Pass. The national telephone survey in particular provided comprehensive information on the number of households that would be expected to purchase the pass at various prices. This information was then used to forecast revenues from the sale of the pass, as well as gate revenues, across all agencies at various pass prices. In addition, the request for proposals stipulated that the price of the pass "should at least allow the government to break even in the sense that, on average, the sale of the pass does not result in a loss of revenue relative to the revenue that would be received absent the ability to purchase an annual pass." To address this, the researchers also evaluated foregone revenue (total revenues in the absence of the pass program minus total revenues with the pass program) at various pass prices. They determined that the price of the pass would need to be set at $125 or above to come close to revenue neutrality, assuming gate entrance fees remained at their current level. At the time of the study, $125 was equal to the cost of an annual pass for California's state parks, and was less than the price of an annual pass for Parks Canada. A novel addition to their analysis was the use of Golden Eagle and National Parks Pass sales data to calibrate hypothetical willingness-to-pay values with real choices. Now that the Interagency Annual Pass has been available for the last ten years, this calibration can be updated using current data on the number of passes sold at a price of $80. This will provide some indication of how pass sales and associated revenues might be expected to change at different pass prices. The details of this analysis are presented later in this report.

## Recent Reports on NPS Recreation Revenues

This section focuses on the National Park Service, though the conclusions are generally applicable across all FLREA agencies. GAO (2015) found that total funding for the National Park Service (NPS) has not kept pace with inflation in recent years, making FLREA revenue an increasingly important part of total NPS funding. Recognizing this increasing importance, GAO recommended that NPS periodically review entrance fees for potential updates. GAO also recommended amendments to FLREA so that the federal agencies can adjust pass prices, in particular the $10 lifetime Senior Pass.

OIG (2015) examined opportunities for the National Park Service (NPS) to increase its recreation program revenues, focusing on the three largest sources of recreation revenues: park-unit entrance fees, interagency passes, and commercial bus tour fees. OIG recommended that NPS establish intervals for periodic reviews to ensure that prices for these three revenue sources remain up to date. In particular, OIG recommended updating the price of the $80 Annual Pass.[12]

## Agency-level Study

This section summarizes data on FLREA revenues collected by the agencies in recent years.

### National Park Service (NPS)

NPS service-wide revenues from the sale of single-park annual passes, the Interagency Annual Pass, and daily admission/entrance fees from 2007 to 2016 are shown in Figure 1. In general, revenues from all sources have seen large increases since 2014, both in nominal dollars and after adjustment for inflation. Revenue from the sale of single-park annual passes has increased by about 25% since 2014, revenue from the sale of the Interagency Annual Pass has increased by nearly 70%, and revenue from entrance fees has increased by about 45%. This boost in revenues is partly due to increased visitation to NPS sites, which could be related to the 2016 NPS Centennial and efforts such as the ‘Find Your Park’ campaign. Although finalized 2016 visitation data are not yet available, many parks are already reporting record-breaking visitation.

[12] The National Park Service Centennial Act of 2016 increased the price of the lifetime Senior Pass from $10 to $80, and introduced a new annual Senior Pass, priced at $20. Going forward, the price of the lifetime Senior Pass is set equal to the price of the Interagency Annual Pass. Future changes in the price of the Interagency Annual Pass will affect the price of the lifetime Senior Pass, though not the annual Senior Pass, which remains at $20 under the law.

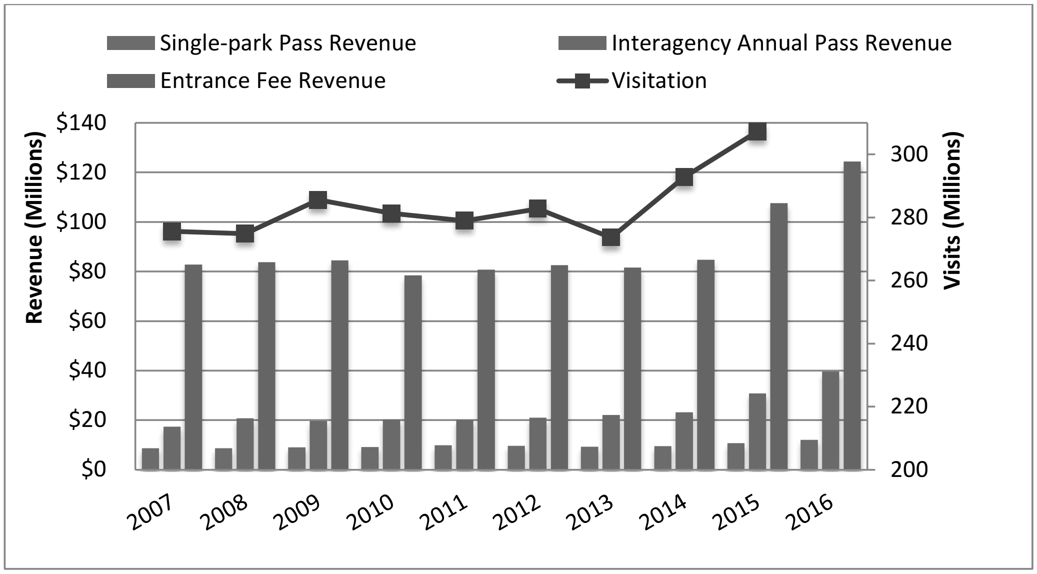


Figure 1. NPS Service-wide Revenues and Visitation, 2007-2016

## U.S. Fish and Wildlife Service (FWS)

Data for FY 2013 through FY 2015 show that FWS visitation and fee revenues followed a similar pattern to that of NPS, though with a less dramatic increase in FY 2015 (Figure 2). However, in FY 2016 FWS saw a drop in fee revenues, as opposed to NPS' continued increase.

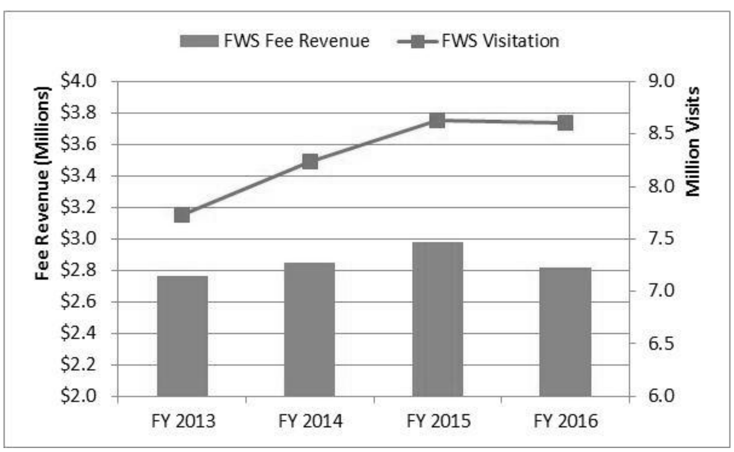


Figure 2. FWS Fee Revenue and Visitation, FY13-FY16 (34 Sites)

## Bureau of Land Management (BLM)

As shown in Figure 3, BLM has seen about a 7 percent increase in visitation over the past four years, from an estimated 58 million visits in FY 2013 to more than 62 million visits in FY 2016. Meanwhile, standard amenity fee revenues have increased by nearly 20 percent.[13]

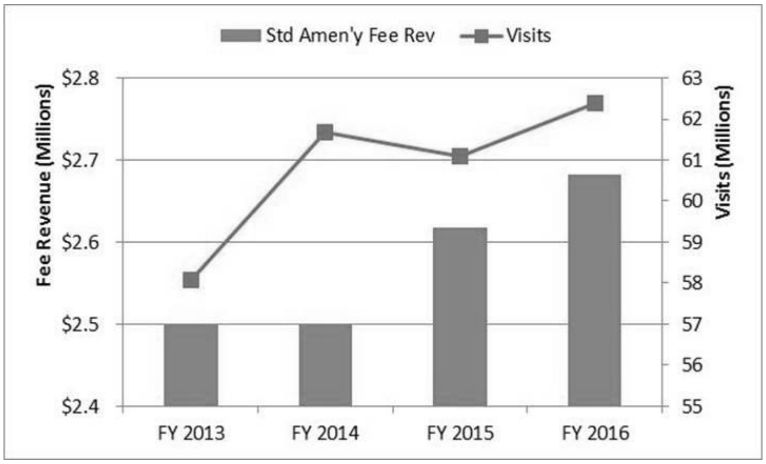


**Figure 3. BLM Fee Revenue and Visitation, FY 2013 – FY 2016**

Figure 4 shows sales of the Interagency Pass at BLM sites. The $80 Annual Pass saw a steady increase from 3,858 passes in FY 2012 to 7,506 in FY 2015. This was followed by a fall to 5,511 passes sold in FY 2016. This may be an effect of the NPS Centennial in 2016, with more BLM site users also visiting NPS sites, and purchasing their passes at those sites. In contrast, sales of the senior pass have continued to increase, from 16,186 in FY 2012 to 21,497 in FY 2015, and 22,722 in FY 2016.

[13] Source: BLM Public Land Statistics (PLS). Other forms of fee revenue reported by BLM in PLS include expanded amenity fee permits; special area permits; commercial competitive, group, and event permits; and leases.

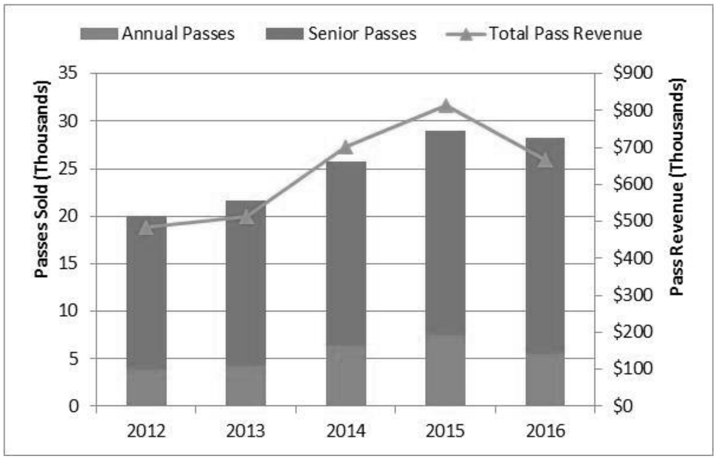


Figure 4. Annual and Senior IA Passes Sold at BLM Sites (2012-2016)

## U.S. Forest Service (USFS)

National forests received nearly 150 million visits in FY 2015.[14] As shown in Figure 5, USFS sold an increasing number of both Annual and Senior Passes in FY 2015 and FY 2016. Senior Passes make up the majority of passes sold by USFS: 78% in FY 2015 and FY 2016. This is comparable to BLM's pass sales, where Senior Passes made up 74% of the total in FY 2015 and 80% in FY 2016.

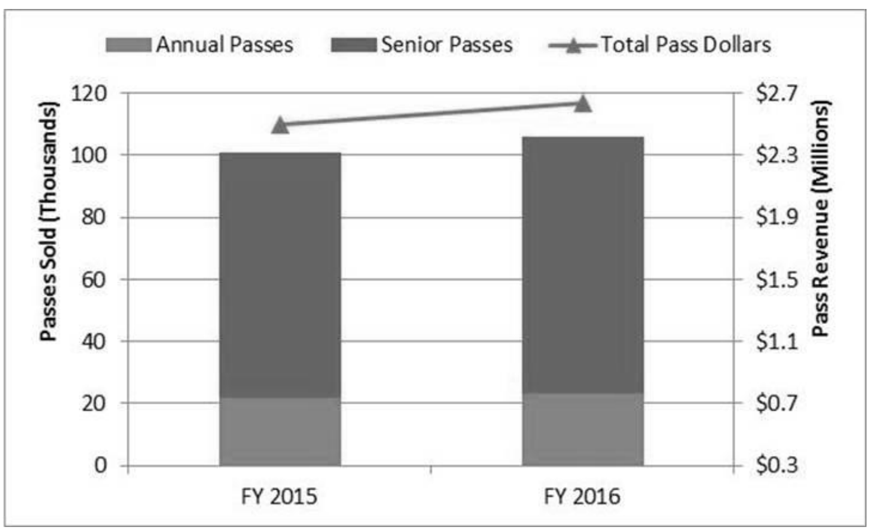


Figure 5. Annual and Senior IA Passes Sold at USFS Sites (2015, 2016)

[14] The USFS National Visitor Use Monitoring (NVUM) program aims to survey visitation at all USFS units once every five years. No unit has yet been surveyed enough times to allow for reporting on trends or use patterns. [Source: US Forest Service (2015) National Visitor Use Monitoring Survey Results; Data Collected FY 2011 through FY 2015 https://www.fs.fed.us/recreation/programs/nvum/pdf/508pdf2015_National_Summary_Report.pdf].

USFS makes a relatively large proportion of their fee revenue from sales of passes for particular USFS sites, such as multi-day, weekly, season, annual and "grand annual" passes; and passes for a household or vehicle; and "joint" passes such as the $50 joint pass covering both Arapaho National Recreation Area and Rocky Mountain National Park. FY 2016 fee and pass revenue data for 73 National Forests included prices for daily use fees and/or passes for 60 of these 73 National Forests, and an additional 14 USFS units that charge fees. Out of these 74 units, 72 charge a daily use fee,[15] and 45 units offer an annual pass. Table 4 summarizes USFS fees and pass prices for FY 2016.

**Table 4. USFS Fees Summary (FY 2016)**

| Revenue Source | Type of Fee/Pass | Price | # of Units Offering |
|---|---|---|---|
| Day Use Fees | per person | $2-$12 | 72 |
| | per bicycle | $3 | 1 |
| | bus | $10 | 1 |
| Passes | per person | $2-$12 | 72 |
| | per bicycle | $3 | 1 |
| | bus | $10 | 1 |
| | 3-day | $10 | 2 |
| | 7-day | $15-$20 | 2 |
| | week | $10-$15 | 5 |
| | season | $40 | 1 |
| | seasonal | $25 | 1 |
| | season/off season | $30/$20 | 1 |
| | annual | $15-$80 | 45 |
| | grand annual | $40 | 1 |
| | vehicle | $18-$20 | 1 |
| | household | $25-$45 | 2 |

Source: UFSF data.

[15] Two of these units charge a one-time fee that allows several days of use: White River, and Uinta-Wasatch-Cache.

As shown in Figure 6, for FY 2016, about three-quarters of fee revenue came from such single-site passes, with the remaining quarter coming from amenity fees deposited by visitors in on-site fee-deposit vaults, or "fee tubes."

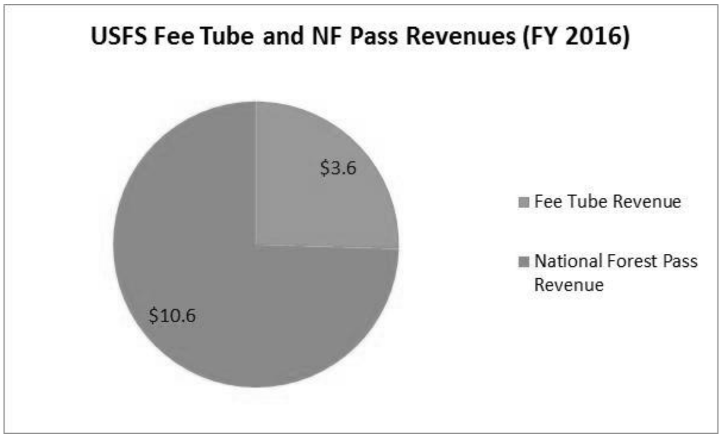


Figure 6. USFS Revenues (FY 2016)

## U.S. Army Corps of Engineers (USACE)

The U.S. Army Corps of Engineers (USACE) joined the Interagency Pass Program in 2016, adding recreational opportunities at USACE's 403 lakes and river projects in 43 states. As shown in Figure 7, visitation at USACE sites ranged from 330 million to 362 million over 2007 to 2012, making USACE the agency with the largest visitation. Unlike USFS, USACE receive most of their revenue in day use fees, rather than in USACE passes: 11 to 13 percent during 2007 to 2015, compared to USFS's 75 percent for 2016.

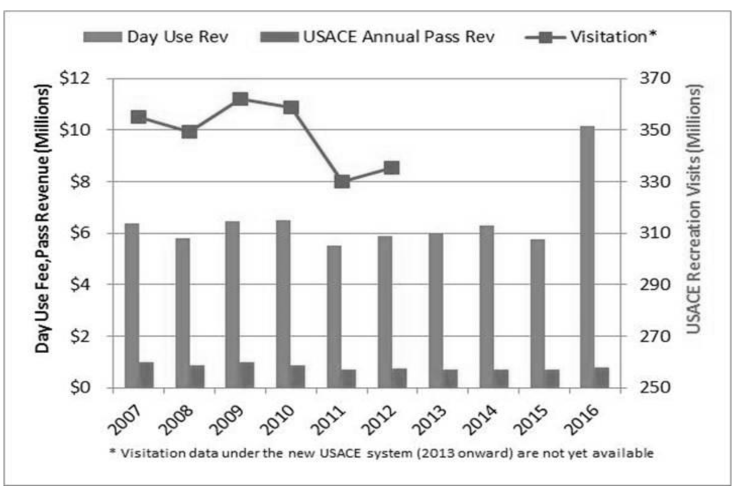


Figure 7. USACE Revenues and Visitation, 2007-2016

## Fee Prices Charged at Sites

In addition to trends in total revenues and visitation, prices represent another important piece of information. There is some variety in how entrance fees and amenity fees are set by the different agencies. For example, as shown in 4, USFS fees vary by site, length of time, and season. FWS fees charged at 34 refuges include single-site annual passes ranging from $10 to $30, and daily per-vehicle fees ranging from $2 to $8.[16] The US Army Corps of Engineers (USACE) joined the FLREA agencies on January 1, 2016, and at this time they raised their per-vehicle fee from $2.50 to $5, and the price of their USACE annual pass from $30 to $40.[17]

We considered the relationship between visitation and entrance fees. For USFS we considered daily fees for 49 National Forests for which we had visitation figures. In FY 2016, there was relatively low correlation (a Pearson's correlation coefficient of 0.15) between daily fees and visitation. For FWS data from FY 2013 to FY 2016, there is a positive correlation between visitation and fee levels: about 0.46 for daily entrance fees, and 0.55 for annual fees, over the four-year period, indicating that more popular refuges tend to have higher fees. This correlation seems to be growing stronger over time; in the absence of price changes this indicates that popular refuges are becoming more popular.

We were able to obtain detailed data on access fees for NPS sites. Although the price of the Interagency Annual Pass has remained at $80, park entrance fees and the price of single-park annual passes have changed over time, especially after the moratorium on fee increases was lifted in 2014. For those parks that charge an entrance fee, Figure 8 shows the average per-person and per-vehicle entrance fee charged from 2007 to 2016, as well as the average price of single-park annual pass for those parks that offer such passes.

[16] Kaua'i NWR Complex charges $5 per person, rather than a per-vehicle fee.
[17] Future research will examine how these price changes impacted visitation at USACE sites.

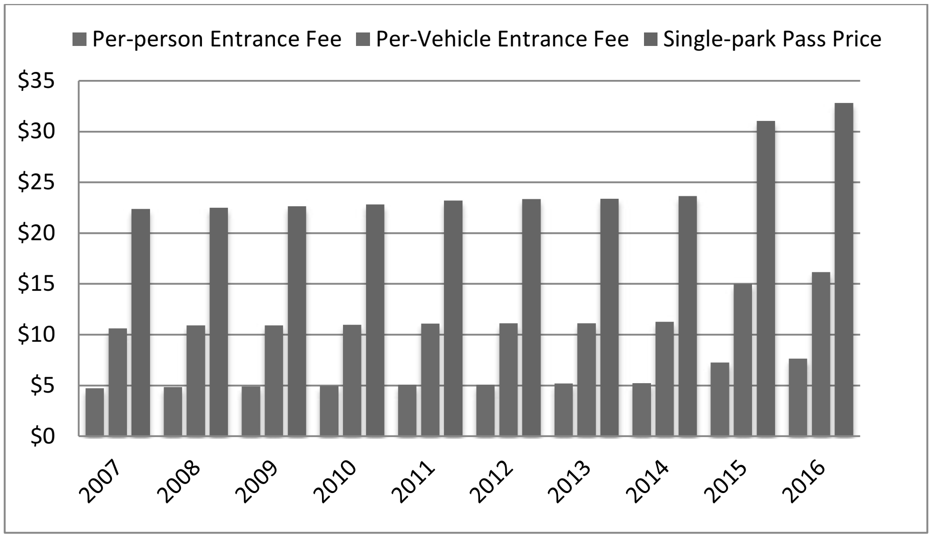


**Figure 8. Average Per-Person Entrance Fee, Per-Vehicle Entrance Fee, and Individual Single-Park Pass Price (NPS Sites, 2007-2016)**

Over that time period, per-person entrance fees increased by about 60% on average (39% when adjusted for inflation), and per-vehicle entrance fees have increased by more than 50% (31% when adjusted for inflation). Just since 2014, per-person and per-vehicle entrance fees have increased by more than 40% on average. The average price of a single-park annual pass has increased by about 45% since 2007 (25% when adjusted for inflation) and by more than 35% since 2014. The large increases since 2014 are a result of NPS lifting the moratorium that year and applying fee increases using the updated pricing structure shown in Table 1. As shown in Table 5, the equivalent annual percentage increase in entrance fees and single-park pass prices from 2007 to 2016 would be about 3 to 5 percent.

**Table 5. NPS Average Entrance Fees**

| | Per-Person Entrance Fee | Per-Vehicle Entrance Fee | Single-Park Annual Pass |
|---|---|---|---|
| Average in 2007 | $4.74 | $10.63 | $22.37 |
| Average in 2016 | $7.65 | $16.16 | $32.82 |
| Percentage increase from 2007 to 2016 | 61% | 52% | 47% |
| Percentage increase from 2007 to 2016, adjusted for inflation | 39% | 31% | 26% |
| Equivalent annual % increase | 4%-5% | 3%-5% | 3%-4% |

There are two important takeaways from this review of recreation fees and revenues over time:

- At least for NPS sites, visitation appears to be relatively unresponsive to price increases associated with site access. There have been large increases in the average price of entrance fees and single-park passes, and revenues across all sources have continued to increase, both in nominal and real dollars. This is consistent with previous findings that entrance fees alone are not a barrier to more frequent visitation of NPS units (Ostergren et al., 2005; Factor, 2007). Of course, entrance and other site access fees typically represent only a small portion of the total trip cost that must be considered when making the decision to visit a recreation site. Further study of the relationship between visitation and access fees for other federal lands could be informative, for example, evaluating visitation data for USACE before and after this agency joined the Interagency Annual Pass program.
- The University of Wyoming's 2006 pricing analysis for the Interagency Annual Pass (discussed in greater detail below) highlighted the fact that whatever base price was ultimately chosen for the pass could be adjusted in advance to account for future increases in gate fees. They explain that while the pass might realistically see cost of living adjustments every three years or so, gate fees could increase more often than that. Assuming that average gate fees increase by 10% over a three-year period, the Interagency Annual Pass would need to include a 10% premium at the outset to ensure that it satisfies revenue neutrality. In reality, while entrance fees across the National Park System (and possibly other federal lands) have increased significantly over the last few years, the price of the Interagency Annual Pass has remained at $80.

## Updating the University of Wyoming's 2006 Pricing Analysis

In 2006, researchers at the University of Wyoming completed an analysis to assist with pricing of the new Interagency Annual Pass (hereafter referred to as Aadland and Shogren, 2006). The basis of the analysis was a nationwide telephone survey administered to two independent strata: a nationally representative sample of U.S. households obtained through random digit dialing (RDD sample) and a random sample of households known to the National Park Foundation to have purchased a National Parks Pass between April 2004 and March 2005, which included mainly those households that purchased the pass online (NPF sample). The analysis is based on the assumption that an individual household will choose to buy the new Interagency Annual Pass if the benefits of doing so outweigh the costs. It is initially assumed that the primary motivation for purchasing the pass is based solely on its economic value; that is, people will purchase the pass if it reduces their expected costs associated with visitation to federal recreation sites.

The policymaker's decision is to choose the price of the pass to maintain revenue neutrality; i.e., total revenues across all agencies participating in the pass program will not be less than total revenues in the absence of the pass program.

To determine how much respondents would be willing to pay for the new Interagency Annual Pass, the study used a nonmarket valuation method known as Contingent Valuation (CV). After a short description of the new pass, households that had visited federal recreation lands in the last two years were presented with a dichotomous choice CV question in which they were asked if they would be willing to purchase the pass at a randomly selected price, ranging from $25 to $165. After responding 'yes' or 'no,' they were asked a follow-up CV question to more precisely determine their actual willingness-to-pay for the pass. If the respondent answered 'no' to the first price, they were presented with a lower price and asked if they would be willing to purchase the pass. If the respondent answered 'yes' to the first price, they were presented with a higher price and asked if they would be willing to purchase the pass. Using the results from this series of questions and scaling to the relevant population of potential pass purchasers, Aadland and Shogren (2006) were able to project the number of households that would be expected to purchase the pass at various prices. To do so, they rely on two different estimates:

1. Unconditional estimates – these estimates do not rely on any econometric model, but rather, are derived directly from households' responses to the two CV questions. For example, if a respondent said 'yes' to a pass price of $65, but 'no' to a pass price of $85, their true willingness-to-pay is assumed to be the midpoint of this interval, or $75. If a respondent said 'yes' to a pass price of $65 and 'yes' to a pass price of $85, they are assigned a willingness-to-pay value of the high price plus $10, or $95 in this example. Finally, if a respondent said 'no' to a pass price of $65 and 'no' to a pass price of $45, they are assigned a willingness-to-pay value equal to half of the lower price, or $22.50.

2. Conditional estimates – these estimates are derived from an econometric model, specifically, an interval regression model. There is a probability associated with each household's possible series of responses to the two CV questions – yes/yes, no/no, yes/no, and no/yes. These probabilities are used to create a log likelihood function, and the regression coefficients are then chosen to maximize this function. Predicted willingness-to-pay estimates for every household in the sample can then be calculated based on these results.

As with any application of the Contingent Valuation Method, survey respondents are asked to make a hypothetical purchasing decision. However, since they are not actually required to pay what they say they will, respondents may overstate their willingness-to-pay. To address this possible hypothetical bias, Aadland and Shogren (2006) used outside information on real market transactions to 'calibrate' their projected demand estimates. Specifically, revenues from the sale of the National Parks Pass and the Golden Eagle Pass were used to scale the projected Interagency Annual Pass revenues (and number of pass-holders, which is just total revenue divided by price) in an effort to better reflect the actual purchasing decisions of consumers. Now that we have ten years of sales data for the Interagency Annual Pass at a price of $80, we can use this information to update the external calibration for hypothetical bias and more accurately capture current demand for the pass. Across all agencies, sales of the Interagency Annual Pass from 2009 to 2014 were as follows:

**Table 6. Interagency Annual Passes Sold by Year and by Agency**

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|
| BLM | 2,434 | 2,765 | 3,874 | 3,858 | 4,267 | 6,348 |
| FWS | 1,667 | 1,771 | 1,922 | 1,819 | 2,014 | 1,926 |
| NPS | 243,281 | 259,580 | 251,779 | 262,678 | 276,824 | 290,035 |
| BOR | 29 | 48 | 56 | 62 | 161 | 20 |
| USFS | 18,287 | 18,329 | 18,469 | 18,537 | 17,557 | 20,871 |
| Central Sales | 21,300 | 22,178 | 18,942 | 16,948 | 18,363 | 23,360 |
| Third Party | 3,144 | 6,387 | 7,842 | 10,933 | 10,344 | 13,456 |
| Total | 290,142 | 311,058 | 302,884 | 314,835 | 329,530 | 356,016 |

Based on the last three years that data are available, total Annual Pass sales have averaged around 333,460 per year at a pass price of $80. This price/quantity point is used to calibrate the unconditional and conditional demand estimates from Aadland and Shogren (2006). For instance, if their estimates predicted that there would be 450,000 passes demanded at a price of $80, but we know there were only 333,460 passes sold at a price of $80, then we divide the number of predicted passes demanded at each price by a factor of 1.35 (450,000/333,460). This is essentially shifting the entire demand curve to more accurately project the number of passes that could be expected to be sold at various prices. We focus on the RDD sample only since the NPF sample accounts for a very small and specific group of pass purchasers from 2006. As noted by Aadland and Shogren (2006), if the two samples were combined and weighted to reflect their relative population sizes, the combined results would be virtually indistinguishable from an analysis of the RDD sample alone.

As with most goods bought and sold in the marketplace, as the price of the pass increases, the quantity of passes demanded will decrease, all else constant. The extent of this decrease depends on how responsive people are to price changes, a relationship known as the *price elasticity of demand*. For a particular good, this elasticity is calculated as the percentage change in quantity demanded divided by the percentage change in price. An elasticity less than one in absolute value shows that demand is inelastic – that is, people are relatively unresponsive to price changes, and the percent change in quantity demanded is less than the percent change in price. In this case, revenues (price times quantity sold) will increase as the price increases; additional revenues from people who continue to purchase the pass is greater than the loss in revenue from those who no longer purchase the pass. Conversely, an elasticity greater than one in absolute value shows that demand is elastic – that is, people are more responsive to price changes, and the percent change in quantity demanded is greater than the percent change in price. In this case, revenues will decrease as the price increases; additional revenues from people who continue to purchase the pass do not make up for the loss in revenue from those who no longer purchase the pass due to the higher price.

Using updated calibration factors based on current sales data, we estimate the projected number of pass-holders, price elasticity of demand, and pass revenue (in aggregate across all agencies) for both the unconditional and conditional estimates at various pass prices. These results are shown in Table 7. Based on the unconditional estimates, people are relatively unresponsive to small increases in the price of the pass from the current price of $80 up to about $95. Thus, we see an increase in pass revenue as the pass price increases from $80 up to $95. Beyond that, the estimates predict large decreases in the number of passes sold and therefore, a decrease in pass revenue. The conditional estimates tell a different story - people are relatively responsive to price increases, resulting in a loss in pass revenue as the pass price increases beyond $80. It should be noted that Aadland and Shogren (2006) put more confidence in the unconditional estimates compared to the conditional estimates. This is due to the fact that the econometric model used to generate the conditional estimates tended to do a better job of predicting willingness-to-pay for households on the low end of the willingness-to-pay distribution than on the high end. Because of the poorer fit at the high end, the model tends to incorrectly predict that households will not purchase the pass at high prices (resulting in larger elasticities at high pass prices). Given the difference in the two estimates, we also estimated an econometric model based on households' responses to the first CV question only (ignoring responses to the follow-up question), as the literature has found some evidence of internal inconsistency between responses to the first and second CV questions (Bateman et al., 2001; Cameron and Quiggin, 1994). The results of this model fell between the unconditional and conditional estimates, but aligned more closely with the unconditional estimates. These results predict that demand is

inelastic at price increases from $80 up to about $90 (with pass revenue of $26.6 million), but once the pass price hits around $95 and beyond, demand becomes elastic and pass revenues begin to drop.

**Table 7. Projected Number of Pass-holders, Price Elasticity of Demand, and Pass Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders | Pass-holders | Elasticity | Pass Revenue (millions of dollars) =Pass Price x Pass-holders |
| $60 | 561,233 | | 33.7 | 549,228 | | 33.0 |
| $65 | 403,684 | -3.37 | 26.2 | 509,998 | -0.86 | 33.1 |
| $70 | 399,840 | -0.12 | 28.0 | 451,152 | -1.50 | 31.6 |
| $75 | 391,843 | -0.28 | 29.4 | 353,075 | -3.04 | 26.5 |
| $80 | 333,460* | -2.23 | 26.7* | 333,460* | -0.83 | 26.7* |
| $85 | 320,559 | -0.62 | 27.2 | 274,614 | -2.82 | 23.3 |
| $90 | 310,986 | -0.51 | 28.0 | 235,384 | -2.43 | 21.2 |
| $95 | 308,664 | -0.13 | 29.3 | 215,768 | -1.50 | 20.5 |
| $100 | 279,888 | -1.77 | 28.0 | 196,153 | -1.73 | 19.6 |
| $105 | 273,065 | -0.49 | 28.7 | 176,538 | -2.00 | 18.5 |
| $110 | 206,735 | -5.10 | 22.7 | 156,922 | -2.33 | 17.3 |
| $115 | 189,974 | -1.78 | 21.8 | 137,307 | -2.75 | 15.8 |
| $120 | 189,507 | -0.06 | 22.7 | 137,307 | 0.00 | 16.5 |

*actual

NB: Shading indicates inelastic portions of the demand curve (estimated elasticity of demand less than 1.0 in absolute value).

Next we calculate projected gate revenues at various Interagency Annual Pass prices, following the approach taken by Aadland and Shogren (2006). Each household has a particular willingness-to-pay for the pass, and the most they should be willing to pay for the pass is the amount they expect to spend at the gate for all sites they plan to visit that year. They will purchase the pass if their willingness-to-pay is greater than or equal to the price of the pass. If their willingness-to-pay is less than the price of the pass, they won't purchase the pass, but it is assumed that they will pay their exact willingness-to-pay in gate entrance fees at various recreation sites. For example, say the pass costs $80 but a household is only

willing to pay $60 for it. Since their willingness-to-pay is less than the price of the pass, they will not purchase it, but may instead visit a park that charges a $20 entrance fee three times in one year, or alternatively, they may visit a site that charges a $10 entrance fee six times in one year, spending their exact $60 willingness-to-pay to access federal recreation sites. This approach assumes that households do not systematically over or underestimate the expected number of trips to federal recreation sites, and that the decision to purchase the pass is based solely on its economic value. Therefore, at a particular pass price, total gate revenue is calculated by summing willingness-to-pay for all households with willingness-to-pay less than the price of the pass, scaled to the relevant population. Table 8 shows projected pass revenue, gate revenue, and total revenue (pass revenue + gate revenue) at pass prices ranging from $60 to $120. These estimates are calibrated for hypothetical bias, and again, represent totals across all agencies participating in the pass program.

**Table 8. Projected Pass Revenue, Gate Revenue and Total Revenue (Pass+Gate) at Pass Prices from $60 to $120**

| | Unconditional Estimates | | | Conditional Estimates | | |
|---|---|---|---|---|---|---|
| Pass Price | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) | Pass Revenue (millions of dollars) | Gate Revenue (millions of dollars) | Total Revenue (millions of dollars) |
| $60 | 33.7 | 181.1 | 214.7 | 33.0 | 213.8 | 246.8 |
| $65 | 26.2 | 191.5 | 217.8 | 33.1 | 216.3 | 249.5 |
| $70 | 28.0 | 191.8 | 219.8 | 31.6 | 220.2 | 251.8 |
| $75 | 29.4 | 192.4 | 221.8 | 26.5 | 227.2 | 253.7 |
| $80 | 26.7* | 194.2 | 220.8 | 26.7* | 228.8 | 255.4 |
| $85 | 27.2 | 195.0 | 222.3 | 23.3 | 233.6 | 256.9 |
| $90 | 28.0 | 195.9 | 223.9 | 21.2 | 236.9 | 258.1 |
| $95 | 29.3 | 197.7 | 227.0 | 20.5 | 238.7 | 259.2 |
| $100 | 28.0 | 199.4 | 227.4 | 19.6 | 240.6 | 260.2 |
| $105 | 28.7 | 199.9 | 228.5 | 18.5 | 242.6 | 261.1 |
| $110 | 22.7 | 208.2 | 230.9 | 17.3 | 244.7 | 262.0 |
| $115 | 21.8 | 209.0 | 230.9 | 15.8 | 246.8 | 262.6 |
| $120 | 22.7 | 209.0 | 231.8 | 16.5 | 246.8 | 263.3 |

*actual

The unconditional estimates show pass revenue increasing as the price of the pass increases from the current price of $80 up to about $95, and gate revenues and total revenues continue to increase as the price of the pass increases. The conditional estimates show pass revenue decreasing at prices beyond $80, but gate revenues and total revenues steadily increase as the price of the pass increases.

Finally, we calculate foregone revenue, again following the approach taken by Aadland and Shogren (2006). Foregone revenue is simply total revenues in the absence of the pass program minus total revenues with the pass program. Setting the price of the pass in a way that doesn't sacrifice substantial revenues (in aggregate across all agencies) would require foregone revenue to approach zero. This would imply that the program is revenue neutral. Total revenues with the pass program are shown above in Table 8.

**Table 9. Projected Foregone Revenue at Pass Prices from $60 to $120**

| | Unconditional Estimates | Conditional Estimates |
|---|---|---|
| Pass Price | Foregone Revenue (millions of dollars) | Foregone Revenue (millions of dollars) |
| $60 | 27.1 | 21.3 |
| $65 | 25.4 | 18.6 |
| $70 | 23.6 | 16.3 |
| $75 | 21.4 | 14.3 |
| $80 | 18.8 | 12.6 |
| $85 | 17.9 | 11.1 |
| $90 | 16.6 | 10.0 |
| $95 | 16.4 | 8.9 |
| $100 | 13.6 | 7.8 |
| $105 | 12.1 | 6.9 |
| $110 | 10.1 | 6.1 |
| $115 | 9.9 | 5.4 |
| $120 | 7.9 | 4.7 |

To estimate total revenues in the absence of the pass program, we simply sum willingness-to-pay for every household in the sample, and scale it to the relevant population. This assumes that, if a household does not have the option to purchase the Interagency Annual Pass, they will simply spend their exact willingness-to-pay for the pass on gate entrance fees at federal recreation sites. Estimates of foregone revenue at various pass prices, also calibrated for hypothetical bias, are shown in Table 9. Under both the unconditional and conditional estimates, foregone revenue is predicted to continue to decrease as the price of the pass increases.

In summary, based on the analysis outlined in Aadland and Shogren (2006), which has been updated using recent sales data, increasing the price of the Interagency Annual Pass from the current price of $80 is expected to result in increased total revenues (and thus decreased foregone revenues) across all agencies participating in the pass program. Further, based on the unconditional estimates, small increases in the price of the Interagency Annual Pass are not expected to greatly reduce demand, meaning revenue from the sale of the pass may also increase if it’s sold at a slightly higher price.

This analysis has assumed that people’s motivation for buying the pass is based on economic considerations alone - that is, they will buy the pass if it reduces their expected costs associated with visitation to federal recreation sites. This is a realistic assumption given that the majority of survey respondents agreed that “the price of the pass compared to the cost of entrance fees” is an important reason to purchase the pass. This was also the primary motivation reported by the Biometrics (2016) survey of central-sales pass purchasers. However, if people are motivated to purchase the pass for other reasons, such as the convenience of not having to make separate entrance fee payments at each site or because they view the pass as a means to maintain and enhance federal lands and facilities, then foregone revenues would be lower at every price point.

Lastly, it is important to note that although the results from Aadland and Shogren (2006) have been updated using current sales data, they are still based on responses to a survey that was conducted more than a decade ago. People now have ten years of experience using the Interagency Annual Pass. A new study would be required to determine whether this experience, or any other factors, have impacted people’s motivations for buying the pass or caused potential pass purchasers to be more or less responsive to price changes than indicated by the results presented here.

## Recommendations for Future Study

There are various reasons that program managers may want to consider conducting a new study of the Interagency Annual Pass. The most recent economic analysis used to assist in pricing of the pass was completed more than ten years ago, and many changes have occurred since then. The Annual Pass is no longer a hypothetical good, and the public now has a decade of experience and familiarity with it. The pass itself has evolved over time. For instance, it provides access to additional federal recreation sites that have been designated since 2006, and recreation sites managed by the U.S. Army Corps of Engineers are now included in the program. In addition, population, per capita income, and prices have increased in the last ten years, and many federal recreation sites now charge higher entrance fees. Any of these factors have the potential to affect people's motivations for purchasing the pass and the amount that they are willing to pay for it.

It may also be worth developing data on prices of alternatives, such as entrance fees and pass prices for State parks, or Parks Canada. For example, California's State parks pass is now priced at $195. A total of 36 States appear to offer an annual pass, and a further 7 States have no charge for visiting State parks.[18] It may also be worth collecting data on entrance fees at other types of substitute activities (e.g., amusement parks). A broader study could look at how entrance fees figure into travel planning; this would inform estimates of sensitivity to price changes. An area offering the potential for general improvements for managing recreation lands is improving visitation estimates. For example, NPS Visitor Use Statistics and the USFS National Visitor Use Model offer rigorous approaches that could be adopted at other agencies.

For a better understanding of the mechanics of revenue neutrality, it could be useful to study the effect of recreation price changes on site conditions, both directly (via maintenance budgets) and indirectly (via visitation levels). A review of the interaction between prices, visitation, and site conditions (e.g., resource conditions, crowding, required maintenance, etc.) at federal and State sites could prove informative as FLREA agencies review their pricing policies. Walls (2016) suggests that seasonal prices are an effective way to address crowding and to deal with maintenance requirements that increase with visitation.

If it is determined that a comprehensive study of the Interagency Annual Pass is warranted, a new pricing analysis could provide updated and more accurate information on: 1. The expected number of Interagency Passes sold and associated revenues at various prices (i.e., the demand curve); 2. The sensitivity of passes demanded to price changes (i.e., the price elasticity of demand); 3. The price of the pass required to

[18] http://usparks.about.com/od/usstateparks/tp/State-Park-Passes.htm

maintain revenue neutrality, if that is determined to be a goal. A survey-based economic valuation method similar to the one outlined in Aadland and Shogren (2006) would most likely be used to obtain this information. It would be worthwhile to survey a random sample of U.S. households, as well as households known to have purchased the Interagency Annual Pass.

In addition to the economic analysis, a detailed evaluation of people's motivations for buying the pass could be undertaken to complement the findings in the survey of centrally sold pass purchasers (Bioeconomics, 2016).[19] These motivations can affect total revenues as well as foregone revenues at various pass prices, as shown in Aadland and Shogren (2006). Additional survey questions similar to those used in the central-sales survey could be included to determine other information that would be useful to the interagency pass program, such as people's satisfaction with the current Interagency Pass and the effectiveness of marketing techniques. A survey of the American public such as this could also potentially provide information about other high-priority issues for the agencies. Detailed discussions with program managers would be necessary to determine the specific goals of such a study. A comprehensive study would most likely require survey development, focus groups, and OMB approval, and would take approximately 18-24 months to complete. Additional funding would be required for a contractor to assist DOI/NPS with this effort.

[19] The Bioeconomics survey covered a variety of topics, including 1) visitor satisfaction, finding high levels of public satisfaction with price, process, pass types, and recreation sites; and 2) motivations for purchasing the pass: 81% of respondents said they purchased the pass to save money, 66% because it is convenient to use and 49% indicated that supporting federal lands conservation was a factor in their decision.

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**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-04-07T08:35:14-04:00
**Importance:** Normal
**Subject:** EKIP Redemption Report for 9/1/2016 - 3/31/2017
**Received:** 2017-04-07T08:35:44-04:00
EKIP Redemption Data 9-1-2016 - 3-31-2017.xlsx

Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong.  Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 3/31/2017**

**FOR INTERNAL USE ONLY**

## Grand Total **95,777**

| | |
|---|---|
| **BLM** | **4,586** |
| Red Rock Canyon National Conservation Area BLM | 999 |
| California BLM Office | 718 |
| Eagle Lake BLM Field Office | 351 |
| National Historic Trails Interpretive Center | 304 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| BLM Eastern States Office | 225 |
| BLM Prineville Office | 220 |
| Klamath Falls Resource Area | 207 |
| Red Rock Canyon National Conservation Area - BLM | 206 |
| Gunnison Gorge National Conservation Area | 204 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Redding BLM Field Office | 111 |
| Alturas BLM Field Office | 99 |
| Nevada BLM Office | 94 |
| Coos Bay BLM District Office | 69 |
| Idaho State Office - BLM | 68 |
| Rio Puerco BLM Field Office | 59 |
| BLM Medford Office | 54 |
| Colorado BLM Office | 21 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Miles City BLM Office | 13 |
| Yaquina Head Oustanding Natural Area | 11 |
| Spokane BLM Office | 9 |
| Royal Gorge BLM Field Office | 4 |
| Utah BLM Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Las Vegas BLM Field Office | 2 |
| Arizona BLM State Office | 2 |
| Wyoming BLM Office | 2 |
| Rock Springs Field Office - BLM | 1 |
| Eugene District BLM Office | 1 |
| **FS** | **7,252** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Stanislaus NF - Mi-Wok District | 500 |
| Lincoln NF - Sacramento District | 397 |

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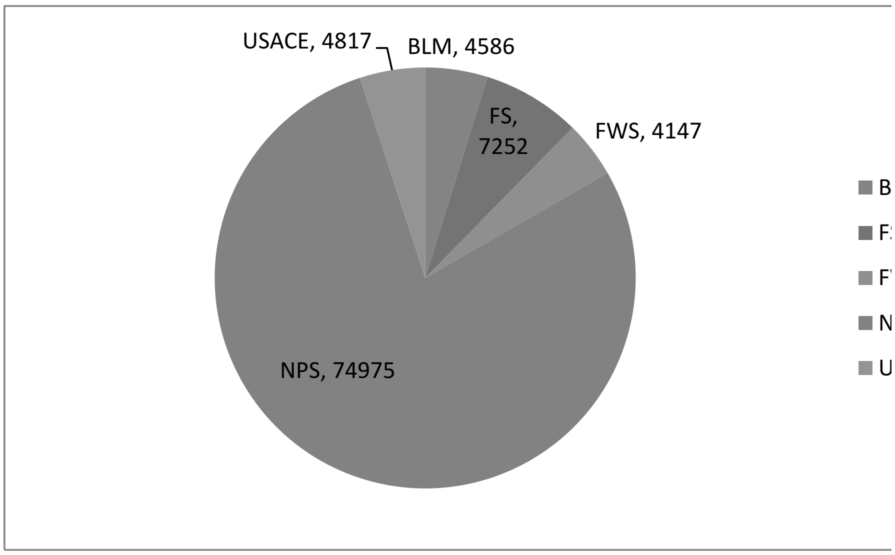
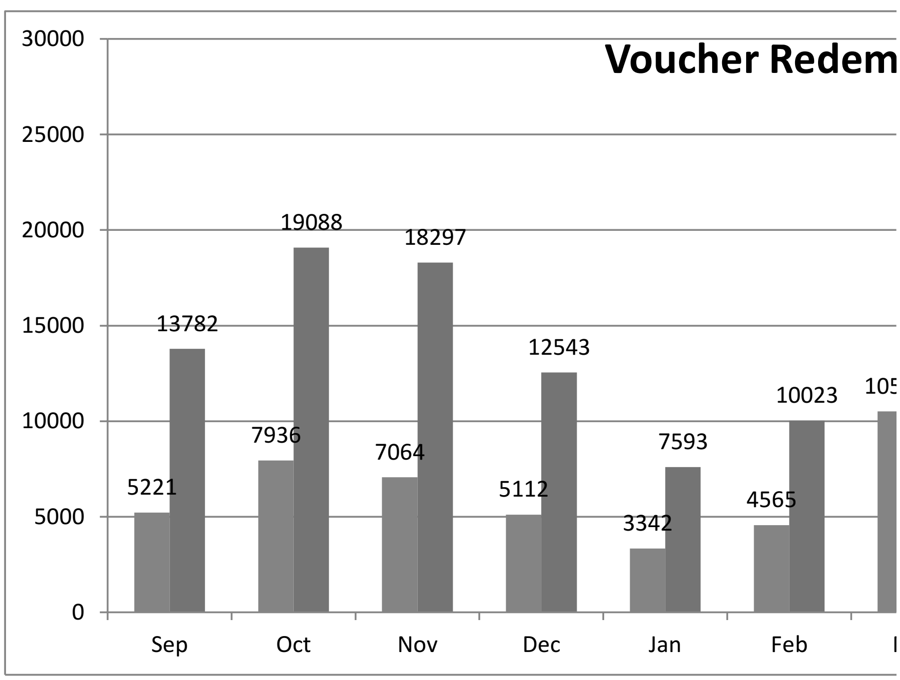
**4.8%**




**7.6%**

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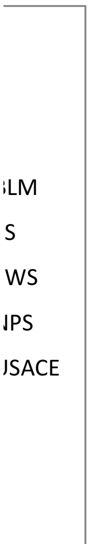


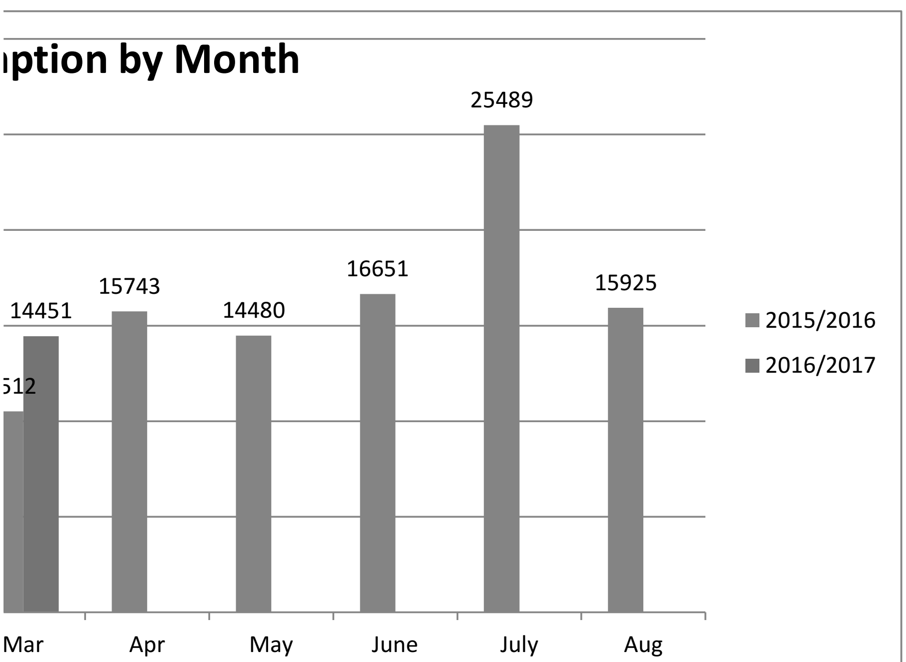

| | |
|---|---|
| Rogue River - Siskiyou NF - Main Office | 368 |
| US Forest Service Region 9 | 343 |
| Umpqua NF - Main Office | 331 |
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Land Between the Lakes | 290 |
| Fremont-Winema NF - Main Office | 247 |
| US Forest Service Regional Office | 238 |
| Chugach National Forest | 184 |
| White Mountain NF - Main Office | 169 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 157 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Ocala NF - Lake George District | 110 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Bighorn NF - Powder River District | 108 |
| Caribou-Targhee NF - Dubois District | 107 |
| Umpqua NF - Diamond Lake Visitor Center | 106 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 101 |
| Olympic NF - Main Office | 93 |
| Eldorado NF - Main Office | 89 |
| Lewis & Clark NF - Main Office | 88 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Carson NF - Main Office | 71 |
| Malheur NF - Emigrant Creek District | 67 |
| Coconino NF - Red Rock Visitor's Center | 65 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Clearwater NF - Main Office | 55 |
| Mt Hood NF - Zigzag District | 54 |
| Umpqua NF - North Umpqua District | 51 |
| Coconino NF - Red Rock District | 43 |
| Colville NF - Republic District | 40 |
| Pike & San Isabel NF - South Platte District | 35 |
| Bighorn NF - Main Office | 34 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 29 |
| Black Hills NF - Mystic District | 28 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| Shasta-Trinity NF - Main Office | 27 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 27 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Humboldt-Toiyabe NF - Bridgeport District | 24 |
| Coronado NF - Main Office | 24 |
| Tonto NF - Main Office | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |

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| Tonto NF - Mesa District | 21 |
| Washington & Jefferson NF - Lee District | 20 |
| Prescott NF - Bradshaw District | 19 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 19 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Sequoia NF - Main Office | 17 |
| Fishlake NF - Fillmore District | 17 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Carson NF - El Rito Station | 17 |
| Kaibab NF - North Kaibab District | 15 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 15 |
| Humboldt-Toiyabe NF - Main Office | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Manti-La Sal NF - Sanpete District | 13 |
| Sawtooth NF - Fairfield District | 13 |
| Caribou-Targhee NF - Westside District | 12 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 12 |
| Tonto NF - Cave Creek District | 12 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Santa Fe NF - Main Office | 11 |
| Idaho Panhandle NF - Coeur d'Alene River District | 10 |
| Pike & San Isabel NF - Salida District | 9 |
| Black Hills NF - Main Office | 9 |
| Sawtooth NF - Main Office | 9 |
| Gifford Pinchot NF - Main Office | 8 |
| Six Rivers NF - Mad River District | 8 |
| Fishlake NF - Main Office | 8 |
| Coconino NF - Main Office | 8 |
| Manti-La Sal NF - Main Office | 8 |
| Kaibab NF - Williams District | 7 |
| Fishlake NF - Fremont River District | 6 |
| Sawtooth NF - Minidoka District | 6 |
| Flathead NF - Tally Lake District | 6 |
| Coconino NF - Mogollon Rim District | 6 |
| Bighorn NF - Medicine Wheel/Paintrock District | 6 |
| White River NF - Dillon District | 5 |
| Nebraska National Forest - Pine Ridge District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| Kaibab NF - Main Office | 5 |
| Umatilla NF - Walla Walla District | 5 |
| Willamette NF - McKenzie River District | 4 |
| Olympic NF - Pacific District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 4 |

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| | |
|---|---|
| Prescott NF - Chino District | 4 |
| Uinta-Wasatch-Cache NF - Evanston District | 4 |
| Colville NF - Newport District | 4 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Okanogan-Wenatchee NF - Cle Elum District | 3 |
| Crooked River National Grasland | 3 |
| Angeles NF - Main Office | 3 |
| Coronado NF - Santa Catalina District | 3 |
| Okanogan-Wenatchee NF - Main Office | 3 |
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Mt Hood NF - Clackamas River District | 3 |
| Klamath NF - Main Office | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| Malheur NF - Main Office | 3 |
| Payette NF - McCall District | 3 |
| Inyo NF - Mammoth Lakes Center | 3 |
| San Bernardino NF - Main Office | 3 |
| Helena NF - Helena District | 2 |
| Beaverhead-Deerlodge NF - Main Office | 2 |
| Cleveland NF - Trabuco District | 2 |
| San Bernardino NF - Front Country District - San Gorgonio Ranger Station | 2 |
| Black Hills NF - Bearlodge District | 2 |
| Willamette NF - Detroit District | 2 |
| Coronado NF - Douglas District | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| Rogue River - Siskiyou NF - Gold Beach District | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Arapahoe & Roosevelt NF - Sulphur District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Green Mountain NF - Middlebury Station | 2 |
| Helena NF - Lincoln District | 2 |
| Fishlake NF - Beaver District | 2 |
| Nez Perce NF - Main Office | 2 |
| San Juan NF - Dolores District | 2 |
| Idaho Panhandle NF - Main Office | 2 |
| Uinta-Wasatch-Cache NF - Logan District | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Sam Houston NF | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| Mt Hood NF - Hood River District | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Umpqua NF - Cottage Grove District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |

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| | |
|---|---|
| San Juan NF - Pagosa District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Siuslaw NF - Main Office | 1 |
| Ottawa NF - Visitor Center | 1 |
| Kaibab NF - Tusayan District | 1 |
| San Juan Public Lands Center - FS | 1 |
| Colville NF - Three Rivers District | 1 |
| Sawtooth NF - Ketchum District | 1 |
| Shasta-Trinity NF - Weaverville Station | 1 |
| Mendocino NF - Main Office | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Los Padres NF - Main Office | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Rogue River - Siskiyou NF - Wild Rivers District | 1 |
| Six Rivers NF - Orleans District | 1 |
| Umatilla NF - Main Office | 1 |
| Sierra NF - Main Office | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| White Mountain NF - Saco District | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Green Mountain NF - Main Office | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| Payette NF - New Meadows District | 1 |
| Sawtooth NF - Stanley District | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Siuslaw NF - Waldport Office | 1 |
| Routt NF - Parks Walden District | 1 |
| Grey Towers National Historic Site | 1 |
| Gallatin NF - Hebgen Lake District | 1 |
| Tahoe NF - Main Office | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Croatan NF - Main Office | 1 |
| **FWS** | **4,147** |
| J.N. "Ding" Darling National Wildlife Refuge | 2,178 |
| Sam D. Hamilton Noxubee NWR | 392 |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 350 |
| Arthur R. Marshall Loxahatchee NWR | 231 |
| St. Marks National Wildlife Refuge | 161 |
| Two Rivers National Wildlife Refuge | 160 |

**4.3%**

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| | |
|---|---|
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| Back Bay NWR | 91 |
| Merritt Island National Wildlife Refuge | 83 |
| DeSoto National Wildlife Refuge | 67 |
| Bombay Hook National Wildlife Refuge | 65 |
| Nisqually NWR | 58 |
| Sacramento NWR | 36 |
| Chincoteague NWR | 19 |
| Fish and Wildlife Service Regional Office | 18 |
| National Elk Refuge | 10 |
| Don Edwards San Francisco Bay NWR | 9 |
| Ottawa National Wildlife Refuge | 3 |
| Parker River National Wildlife Refuge | 3 |
| Bosque del Apache NWR | 1 |
| Ridgefield NWRC | 1 |
| **NPS** | **74,975** |
| San Juan National Historic Site | 6,696 |
| Assateague Island National Seashore | 4,762 |
| Colonial National Historical Park | 3,290 |
| Lake Mead National Recreation Area | 3,252 |
| Fort McHenry National Monument | 3,059 |
| Yosemite National Park | 2,642 |
| Indiana Dunes National Lakeshore | 2,313 |
| Chesapeake & Ohio Canal NHP | 2,206 |
| Chamizal National Memorial | 2,133 |
| Hopewell Culture National Historical Park | 2,046 |
| Mount Rainier National Park | 1,935 |
| Channel Islands National Park | 1,884 |
| Grand Canyon National Park | 1,863 |
| Cuyahoga Valley National Park | 1,801 |
| Joshua Tree National Park | 1,797 |
| Zion National Park | 1,412 |
| Garfield National Historic Site | 1,307 |
| Great Falls Park | 1,176 |
| Rocky Mountain National Park | 1,138 |
| Acadia National Park | 1,133 |
| Richmond National Battlefield Park | 1,081 |
| Arches National Park | 934 |
| Walnut Canyon National Monument | 924 |
| Petroglyph National Monument | 923 |
| Yellowstone National Park | 859 |
| Harpers Ferry National Historical Park | 855 |
| Cedar Breaks National Monument | 743 |

**78.3%**

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| | |
|---|---|
| Death Valley National Park | 695 |
| Catoctin Mountain Park | 688 |
| Colorado National Monument | 656 |
| Sequoia & Kings Canyon National Park | 608 |
| Petrified Forest National Park | 574 |
| Pinnacles National Monument | 573 |
| San Francisco Maritime National Historical Park | 565 |
| Montezuma Castle National Monument | 516 |
| Sleeping Bear Dunes National Lakeshore | 509 |
| Tumacacori National Historical Park | 494 |
| Lowell National Historical Park | 475 |
| Lewis & Clark National Historical Park | 473 |
| Organ Pipe Cactus National Monument | 466 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 450 |
| Pu'uhonua O Honaunau | 447 |
| Wright Brothers National Memorial | 440 |
| Fort Vancouver National Historic Site | 415 |
| Blue Ridge Parkway (Campgrounds) | 412 |
| Cabrillo National Monument | 403 |
| Everglades National Park | 393 |
| Olympic National Park | 389 |
| Bryce Canyon National Park | 382 |
| Casa Grande Ruins National Monument | 379 |
| Capulin Volcano National Monument | 338 |
| Big South Fork National River & Recreation Area | 313 |
| Castillo de San Marcos National Monument | 310 |
| Big Thicket National Preserve | 287 |
| Hawaii Volcanoes National Park | 273 |
| Gila Cliff Dwellings National Monument | 257 |
| Carlsbad Caverns National Park | 244 |
| Dinosaur National Monument (Passes only sold at UT location)) | 235 |
| Shenandoah National Park - Thornton Gap Entrance | 233 |
| Pictured Rocks National Seashore | 232 |
| Ulysses S Grant National Historic Site | 229 |
| Grand Teton National Park | 222 |
| Florissant Fossil Beds National Monument | 216 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Crater Lake National Park | 196 |
| Tonto National Monument | 195 |
| Hot Springs National Park | 192 |
| Shenandoah National Park - Front Royal Entrance | 188 |
| Badlands National Park | 186 |
| Fort Washington Park | 179 |
| Glacier National Park | 174 |
| Shenandoah National Park - Swift Run Entrance | 171 |

91 entered by BISC on 12/7

| | |
|---|---|
| Saguaro National Park | 164 |
| Fossil Butte National Monument | 161 |
| Mesa Verde National Park | 161 |
| Bents Old Fort Historic Site | 155 |
| Big Bend National Park | 151 |
| Little Rock Central High School NHS | 135 |
| Lava Beds National Monument | 134 |
| Delaware Water Gap National Rec Area | 133 |
| Canyonlands National Park | 131 |
| Bighorn Canyon National Recreation Area | 128 |
| Jewel Cave National Monument | 120 |
| Lassen Volcanic National Park | 113 |
| Great Sand Dunes National Park | 111 |
| Haleakala National Park | 111 |
| Aztec Ruins National Monument | 101 |
| Greenbelt Park | 98 |
| Chickamauga & Chattanooga National Military Park | 94 |
| Saint Gaudens National Historic Site | 87 |
| Antietam National Battlefield | 83 |
| Mammoth Cave National Park | 83 |
| Prince William Forest Park | 78 |
| Craters of the Moon National Monument | 76 |
| Edison National Historical Park | 75 |
| Gulf Islands National Seashore | 74 |
| Sunset Crater Volcano National Monument | 72 |
| Shenandoah National Park - Rockfish Entrance | 71 |
| Whiskeytown National Recreation Area | 71 |
| Obed Wild and Scenic River | 68 |
| Capitol Reef National Park | 64 |
| White Sands National Monument | 62 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| William Howard Taft National Historical Site | 60 |
| Klondike Gold Rush National Historical Park | 60 |
| Devils Tower National Monument | 53 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Golden Spike National Historic Site | 45 |
| Steamtown National Historic Site | 41 |
| Bandalier National Monument | 40 |
| Wind Cave National Park | 40 |
| Canaveral National Seashore | 38 |
| Weir Farm National Historic Site | 37 |
| Timpanogos Cave National Monument | 36 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Padre Island National Seashore | 34 |

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| | |
|---|---|
| Fort Union National Monument | 30 |
| Mount Rushmore National Memorial | 30 |
| Scotts Bluff National Monument | 27 |
| Vicksburg National Military Park | 26 |
| Fort Davis National Historic Site | 24 |
| Wilson's Creek National Battlefield | 23 |
| Guadalupe Mountains National Park | 22 |
| Lincoln Boyhood National Memorial | 21 |
| Theodore Roosevelt National Park - South Unit | 20 |
| Little Bighorn Battlefield National Monument | 20 |
| Pipestone National Monument | 19 |
| Saratoga National Historical Park | 19 |
| Fort Moultrie National Monument | 18 |
| Tuzigoot National Monument | 18 |
| Harry S Truman National Historic Site | 17 |
| Pipe Spring National Monument | 16 |
| Denali National Park & Preserve | 16 |
| Great Smoky Mountains NP - Sugarland VC | 12 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 11 |
| Great Smoky Mountains NP - Oconaluftee Visitor's Center | 10 |
| Chaco Culture National Historical Park | 9 |
| Great Basin National Park | 8 |
| Wupatki National Monument | 7 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| Chickasaw National Recreation Area | 6 |
| National Historic Oregon Trail Interpretive Center | 5 |
| Herbert Hoover National Historical Site | 5 |
| Natural Bridges National Monument | 5 |
| Fort Necessity National Battlefield | 4 |
| Johnstown Flood National Memorial | 4 |
| Carl Sandburg Home National Historic Site | 3 |
| Fort Smith National Historic Site | 3 |
| Great Smoky Mountain NP - Cades Cove Campground | 3 |
| Great Smoky Mountains NP - Smokemont Campground | 3 |
| Valles Caldera National Preserve | 3 |
| Isle Royale National Park | 2 |
| Mississippi National River & Recreation Area | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| Homestead National Monument of America | 1 |
| **USACE** | **4,817** |
| Philpott Lake | 1,349 |
| Mississippi River Project | 876 |
| Wappapello Lake | 355 |

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|---|---|
| Lake Shelbyville | 291 |
| Proctor lake | 261 |
| Falls Lake | 235 |
| Carters | 175 |
| Sandy Lake Recreation Area | 173 |
| Table Rock Lake | 172 |
| Englebright Lake | 168 |
| Gull Lake Recreation Area | 157 |
| Woodruff-Seminole | 150 |
| John H. Kerr Dam and Reservoir | 112 |
| Raystown Lake Project | 72 |
| Greers Ferry Lake | 60 |
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Allatoona | 33 |
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| West Hill Dam | 3 |
| North Hartland Lake | 2 |
| Hensley Lake | 1 |
| Tioga-Hammond Lakes Project | 1 |
| Success Lake | 1 |
| Bay Model Visitor Center | 1 |
| Coralville Lake | 1 |
| Eastman Lake | 1 |
| Abiquiu Lake | 1 |
| Cowanesque Lake Project | 1 |

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**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**From:** Rees, Gareth
**Sent:** 2017-04-25T09:29:27-04:00
**Importance:** Normal
**Subject:** Re: BOR Klamath River Basin Study
**Received:** 2017-04-25T09:29:58-04:00
Klamath Basin Study Appendices.docx
Klamath Basin Study Summary Report.docx

Please find attached a copy of the report

On Mon, Apr 24, 2017 at 1:58 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

OK. Thanks.

On Mon, Apr 24, 2017 at 1:57 PM, Rees, Gareth <gareth_rees@ios.doi.gov> wrote:

I think 45 minutes is plenty of time. I will try and get an electronic version of the report and send to you.
Thanks

On Mon, Apr 24, 2017 at 1:43 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

1. I have a mtg at 2:00 PM for which I would have to leave at 1:45. So if 45 minutes is ample time, I could certainly do it.
2. Is it possible for me to see a draft in advance, or would I get a copy at the mtg?

Thanks Gareth.

On Mon, Apr 24, 2017 at 1:26 PM, Rees, Gareth <gareth_rees@ios.doi.gov> wrote:

Indur
Would you be available to meet with Jim on Friday at 1pm to discuss the BOR Klamath River Basin Study which has yet to be released?

Thanks

--

Gareth C. Rees

Office to the Deputy Secretary

U.S. Department of the Interior

Tel: 202-208-6291

Fax: 202-208-1873

Cell: 202-957-8299

--

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RECLAMATION

*Managing Water in the West*

# Klamath River Basin Study

## SUMMARY REPORT

**December 2016**

**U.S. Department of the Interior**
**Bureau of Reclamation**

**State of California**
**Department of Water Resources**

**State of Oregon**
**Water Resources Department**

# Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The California Department of Water Resource's mission is to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments.

The mission of the Oregon Water Resources Department is to serve the public by practicing and promoting responsible water management through two key goals:

- to directly address Oregon's water supply needs, and
- to restore and protect streamflow and watersheds in order to ensure the long-term sustainability of Oregon's ecosystems, economy, and quality of life.

Cover photo: Mt. McLoughlin and Klamath Lake in the Klamath Basin Area. Photo by Regional Photographer Winetta Owens.

# Klamath River Basin Study
# Summary Report

**December 2016**

**U.S. Department of the Interior**
**Bureau of Reclamation**

## In Partnership with:

**California Department of Water Resources**
**Oregon Water Resources Department**

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# Appendices

# Klamath River Basin Study

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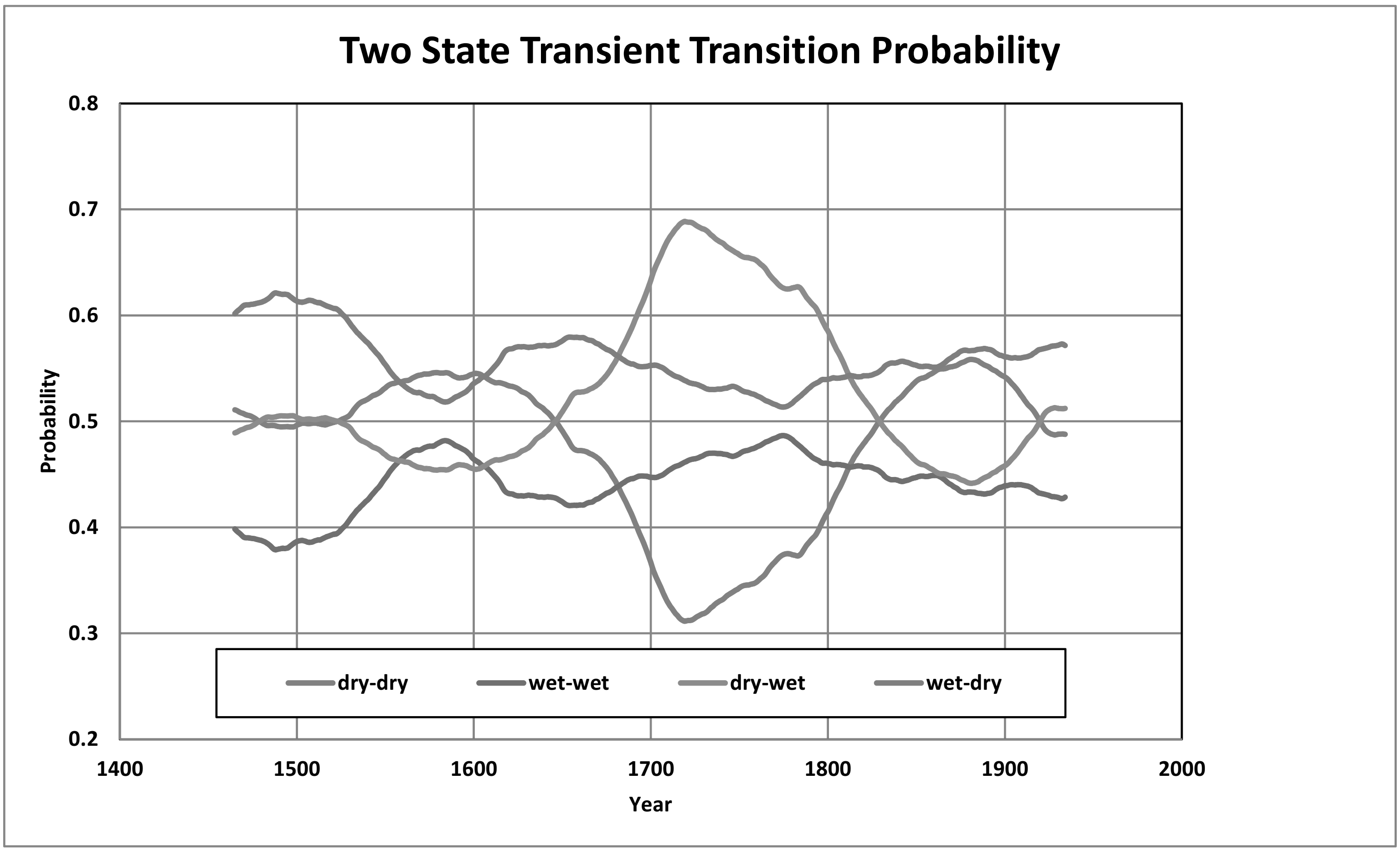

**To:** Al Remley[allisonrremley@fs.fed.us]; Chris Williamson[Chris_Williamson@nps.gov]; Christian.Crowley@ios.doi.gov[Christian.Crowley@ios.doi.gov]; David Ballenger[dballeng@blm.gov]; Diane Stratton[Diane.L.Stratton@usace.army.mil]; Indur Goklany[indur_goklany@ios.doi.gov]; Jerome Jackson[jljackson@usbr.gov]; Jocelyn Biro[JBiro@fs.fed.us]; Julie Cox[jacox@fs.fed.us]; Mary Coulombe[Mary.J.Coulombe@usace.army.mil]; Peggi Brooks[pbrooks@blm.gov]; Phil LePelch[phil_lepelch@fws.gov]; Roseana Burick[Roseana.M.Burick@usace.army.mil]; Ryan Alcorn[ralcorn@usbr.gov]; Simon, Benjamin[Benjamin_Simon@ios.doi.gov]; Traci Kolc[Traci_Kolc@nps.gov]
**From:** Linford, Brooke
**Sent:** 2017-05-01T08:20:09-04:00
**Importance:** Normal
**Subject:** EKIP Redemption Report for 9/1/2016 - 4/30/2017
**Received:** 2017-05-01T08:20:39-04:00
EKIP Redemption Data 9-1-2016 - 4-30-2017.xlsx

Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong.  Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1201 Eye Street, NW
Org Code 2608
Washington, DC 20005

Phone: 202-513-7139

# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 4/30/2017**

**FOR INTERNAL USE ONLY**

| | |
|---|---|
| **Grand Total** | **114,510** |
| **BLM** | **5,334** |
| Red Rock Canyon National Conservation Area BLM | 1,027 |
| California BLM Office | 720 |
| National Historic Trails Interpretive Center | 503 |
| Eagle Lake BLM Field Office | 351 |
| BLM Eastern States Office | 321 |
| Red Rock Canyon National Conservation Area - BLM | 268 |
| BLM Prineville Office | 244 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| Klamath Falls Resource Area | 207 |
| Gunnison Gorge National Conservation Area | 204 |
| Idaho BLM Office | 197 |
| Redding BLM Field Office | 192 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Alturas BLM Field Office | 99 |
| Nevada BLM Office | 95 |
| Coos Bay BLM District Office | 69 |
| Idaho State Office - BLM | 68 |
| Rio Puerco BLM Field Office | 59 |
| Casper Field Office - BLM | 58 |
| BLM Medford Office | 54 |
| Colorado BLM Office | 21 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Miles City BLM Office | 13 |
| Yaquina Head Oustanding Natural Area | 11 |
| Spokane BLM Office | 9 |
| Utah BLM Office | 4 |
| Royal Gorge BLM Field Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Wyoming BLM Office | 2 |
| Las Vegas BLM Field Office | 2 |
| Arizona BLM State Office | 2 |
| Eugene District BLM Office | 1 |
| Rock Springs Field Office - BLM | 1 |
| **FS** | **7,888** |
| Apache-Sitgreaves NF - Lakeside District | 734 |

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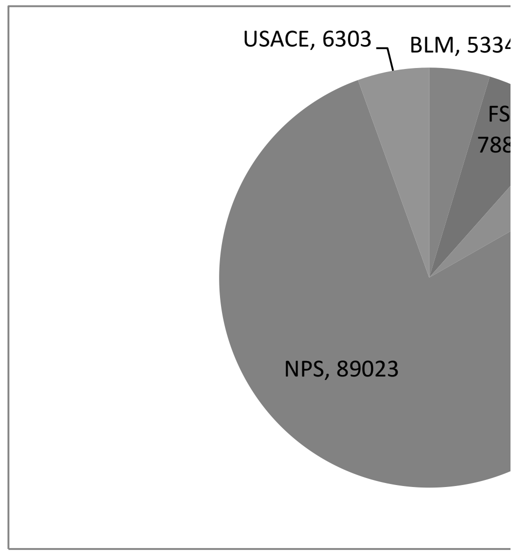
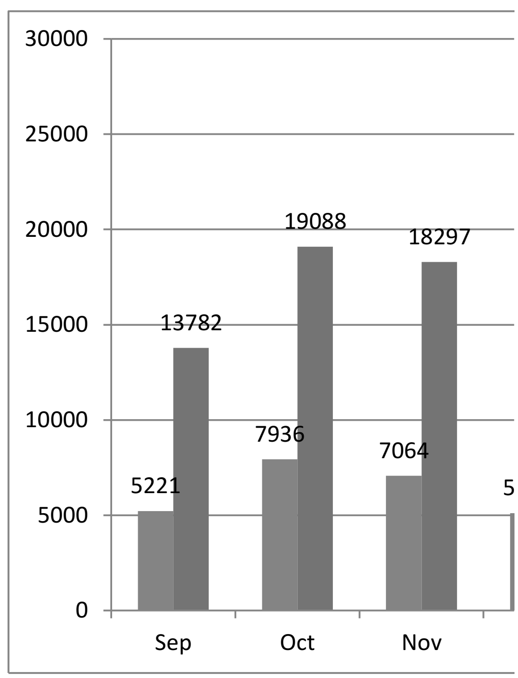
**4.7%**




**6.9%**

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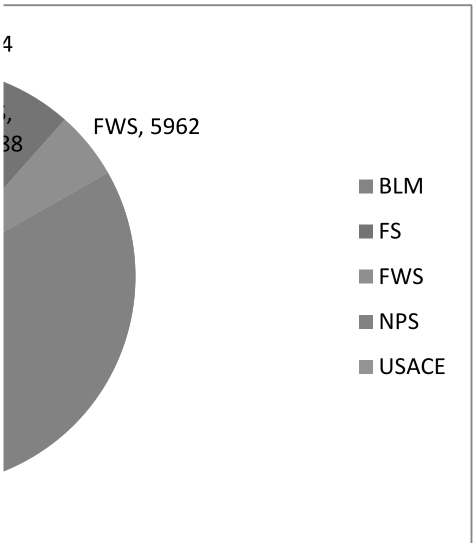


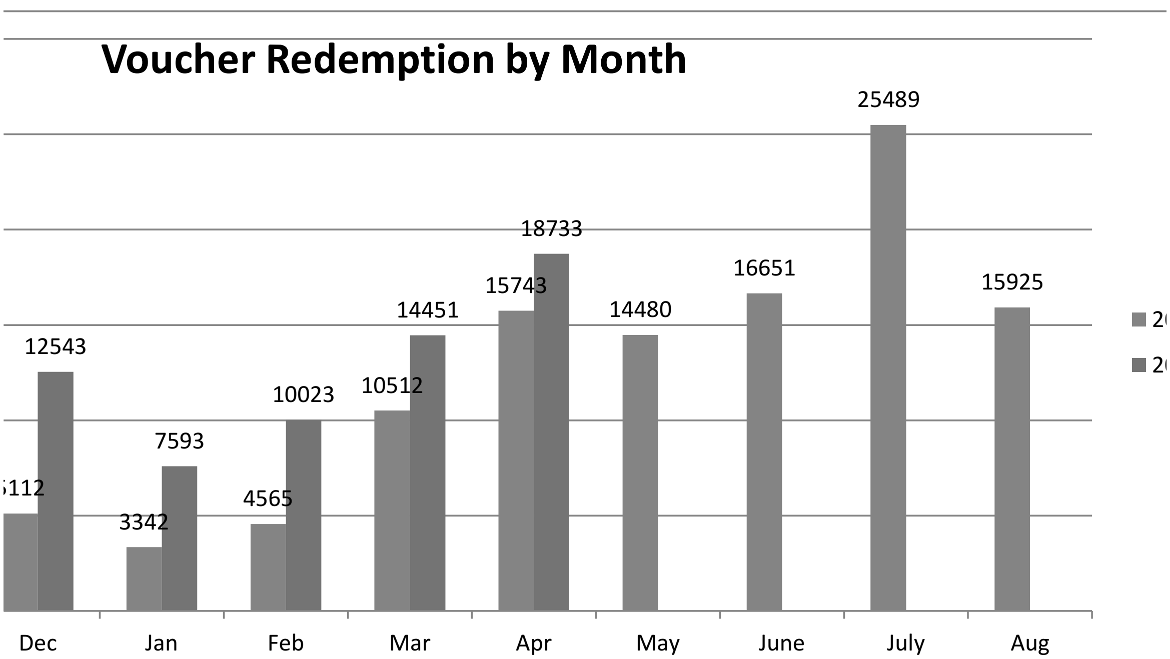

015/2016

016/2017

| | |
|---|---|
| Stanislaus NF - Mi-Wok District | 500 |
| Land Between the Lakes | 454 |
| Lincoln NF - Sacramento District | 397 |
| Rogue River - Siskiyou NF - Main Office | 368 |
| US Forest Service Region 9 | 343 |
| Umpqua NF - Main Office | 331 |
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Lewis & Clark NF - Main Office | 256 |
| Fremont-Winema NF - Main Office | 247 |
| US Forest Service Regional Office | 238 |
| Chugach National Forest | 184 |
| White Mountain NF - Main Office | 169 |
| Ottawa NF - Visitor Center | 167 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 162 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 140 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Ocala NF - Lake George District | 110 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Bighorn NF - Powder River District | 108 |
| Caribou-Targhee NF - Dubois District | 107 |
| Umpqua NF - Diamond Lake Visitor Center | 106 |
| Coconino NF - Red Rock Visitor's Center | 102 |
| Olympic NF - Main Office | 94 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Carson NF - Main Office | 71 |
| Coconino NF - Red Rock District | 67 |
| Malheur NF - Emigrant Creek District | 67 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Clearwater NF - Main Office | 55 |
| Mt Hood NF - Zigzag District | 54 |
| Umpqua NF - North Umpqua District | 51 |
| Colville NF - Republic District | 40 |
| Pike & San Isabel NF - South Platte District | 35 |
| Bighorn NF - Main Office | 34 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 34 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 29 |
| Black Hills NF - Mystic District | 28 |
| Shasta-Trinity NF - Main Office | 27 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| Coronado NF - Main Office | 27 |
| Humboldt-Toiyabe NF - Bridgeport District | 24 |

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|---|---|
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Tonto NF - Main Office | 23 |
| Tonto NF - Mesa District | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 22 |
| Washington & Jefferson NF - Lee District | 20 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Prescott NF - Bradshaw District | 19 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 19 |
| Fishlake NF - Fillmore District | 17 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Sequoia NF - Main Office | 17 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Carson NF - El Rito Station | 17 |
| Kaibab NF - North Kaibab District | 15 |
| Humboldt-Toiyabe NF - Main Office | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Manti-La Sal NF - Sanpete District | 13 |
| Sawtooth NF - Fairfield District | 13 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 12 |
| Gifford Pinchot NF - Main Office | 12 |
| Caribou-Targhee NF - Westside District | 12 |
| Tonto NF - Cave Creek District | 12 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Santa Fe NF - Main Office | 11 |
| Idaho Panhandle NF - Coeur d'Alene River District | 10 |
| Pike & San Isabel NF - Salida District | 9 |
| Black Hills NF - Main Office | 9 |
| Sawtooth NF - Main Office | 9 |
| Manti-La Sal NF - Main Office | 8 |
| Fishlake NF - Main Office | 8 |
| Coconino NF - Main Office | 8 |
| Six Rivers NF - Mad River District | 8 |
| Coronado NF - Santa Catalina District | 7 |
| Kaibab NF - Williams District | 7 |
| Bighorn NF - Medicine Wheel/Paintrock District | 6 |
| Flathead NF - Tally Lake District | 6 |
| Olympic NF - Pacific District | 6 |
| Sawtooth NF - Minidoka District | 6 |
| Coconino NF - Mogollon Rim District | 6 |
| Fishlake NF - Fremont River District | 6 |
| Nebraska National Forest - Pine Ridge District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| White River NF - Dillon District | 5 |
| Umatilla NF - Walla Walla District | 5 |

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|---|---|
| Kaibab NF - Main Office | 5 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 4 |
| Uinta-Wasatch-Cache NF - Evanston District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Prescott NF - Chino District | 4 |
| Willamette NF - McKenzie River District | 4 |
| Colville NF - Newport District | 4 |
| Mt Hood NF - Clackamas River District | 3 |
| Inyo NF - Mammoth Lakes Center | 3 |
| San Bernardino NF - Main Office | 3 |
| Angeles NF - Main Office | 3 |
| Okanogan-Wenatchee NF - Main Office | 3 |
| Malheur NF - Main Office | 3 |
| Okanogan-Wenatchee NF - Cle Elum District | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Arapahoe & Roosevelt NF - Sulphur District | 3 |
| Arapahoe & Roosevelt NF - Boulder District | 3 |
| Crooked River National Grasland | 3 |
| Klamath NF - Main Office | 3 |
| Payette NF - McCall District | 3 |
| Idaho Panhandle NF - Main Office | 2 |
| Cleveland NF - Trabuco District | 2 |
| Uinta-Wasatch-Cache NF - Logan District | 2 |
| Fishlake NF - Beaver District | 2 |
| Black Hills NF - Bearlodge District | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| Coronado NF - Douglas District | 2 |
| Tongass NF - Southeast Alaska Discovery Center | 2 |
| Rogue River - Siskiyou NF - Wild Rivers District | 2 |
| Green Mountain NF - Middlebury Station | 2 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |
| San Bernardino NF - Front Country District - San Gorgonio Ranger Station | 2 |
| San Juan NF - Dolores District | 2 |
| Helena NF - Lincoln District | 2 |
| Willamette NF - Detroit District | 2 |
| Helena NF - Helena District | 2 |
| Rogue River - Siskiyou NF - Gold Beach District | 2 |
| Nez Perce NF - Main Office | 2 |
| Beaverhead-Deerlodge NF - Main Office | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Grey Towers National Historic Site | 1 |
| Siuslaw NF - Main Office | 1 |

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|---|---|
| White Mountain NF - Saco District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Shasta-Trinity NF - Weaverville Station | 1 |
| Mendocino NF - Main Office | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| San Juan Public Lands Center - FS | 1 |
| Umpqua NF - Cottage Grove District | 1 |
| Sawtooth NF - Ketchum District | 1 |
| Colville NF - Three Rivers District | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Los Padres NF - Main Office | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Mt Hood NF - Hood River District | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Routt NF - Hahans Peak/Bears Ears District | 1 |
| Six Rivers NF - Orleans District | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Umatilla NF - Main Office | 1 |
| Croatan NF - Main Office | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| Green Mountain NF - Main Office | 1 |
| Sawtooth NF - Stanley District | 1 |
| Sam Houston NF | 1 |
| Sierra NF - Main Office | 1 |
| Kaibab NF - Tusayan District | 1 |
| Tahoe NF - Main Office | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Payette NF - New Meadows District | 1 |
| Siuslaw NF - Waldport Office | 1 |
| Routt NF - Parks Walden District | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Gallatin NF - Hebgen Lake District | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |
| San Juan NF - Pagosa District | 1 |
| **FWS** | **5,962** |
| J.N. "Ding" Darling National Wildlife Refuge | 2,867 |
| Arthur R. Marshall Loxahatchee NWR | 974 |
| Sam D. Hamilton Noxubee NWR | 392 |

**5.2%**

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| | |
|---|---|
| Hobe Sound NWR Nature Center (also sold at fee booth) | 350 |
| Nisqually NWR | 243 |
| Back Bay NWR | 211 |
| Two Rivers National Wildlife Refuge | 210 |
| St. Marks National Wildlife Refuge | 162 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| Merritt Island National Wildlife Refuge | 83 |
| DeSoto National Wildlife Refuge | 68 |
| Bombay Hook National Wildlife Refuge | 65 |
| Sacramento NWR | 36 |
| Chincoteague NWR | 36 |
| Fish and Wildlife Service Regional Office | 18 |
| National Elk Refuge | 10 |
| Don Edwards San Francisco Bay NWR | 9 |
| Parker River National Wildlife Refuge | 6 |
| Long Island NWR Complex | 4 |
| Bosque del Apache NWR | 3 |
| Ottawa National Wildlife Refuge | 3 |
| Ridgefield NWRC | 1 |
| **NPS** | **89,023** |
| San Juan National Historic Site | 6,698 |
| Assateague Island National Seashore | 4,821 |
| Fort McHenry National Monument | 3,984 |
| Lake Mead National Recreation Area | 3,552 |
| Colonial National Historical Park | 3,552 |
| Yosemite National Park | 3,203 |
| Indiana Dunes National Lakeshore | 2,689 |
| Grand Canyon National Park | 2,659 |
| Zion National Park | 2,564 |
| Chesapeake & Ohio Canal NHP | 2,226 |
| Chamizal National Memorial | 2,163 |
| Hopewell Culture National Historical Park | 2,046 |
| Cuyahoga Valley National Park | 1,993 |
| Joshua Tree National Park | 1,987 |
| Channel Islands National Park | 1,950 |
| Mount Rainier National Park | 1,943 |
| Arches National Park | 1,676 |
| Great Falls Park | 1,532 |
| Garfield National Historic Site | 1,313 |
| Rocky Mountain National Park | 1,252 |
| San Francisco Maritime National Historical Park | 1,194 |
| Acadia National Park | 1,133 |
| Lewis & Clark National Historical Park | 1,107 |

**77.7%**

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| | |
|---|---|
| Richmond National Battlefield Park | 1,081 |
| Harpers Ferry National Historical Park | 997 |
| Fort Vancouver National Historic Site | 967 |
| Petroglyph National Monument | 955 |
| Walnut Canyon National Monument | 938 |
| Pinnacles National Monument | 911 |
| Yellowstone National Park | 865 |
| Death Valley National Park | 809 |
| Sequoia & Kings Canyon National Park | 794 |
| Cedar Breaks National Monument | 743 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 733 |
| Bryce Canyon National Park | 691 |
| Catoctin Mountain Park | 688 |
| Colorado National Monument | 681 |
| Montezuma Castle National Monument | 675 |
| Blue Ridge Parkway (Campgrounds) | 660 |
| Petrified Forest National Park | 649 |
| Tumacacori National Historical Park | 615 |
| Pictured Rocks National Seashore | 613 |
| Lowell National Historical Park | 601 |
| Pu'uhonua O Honaunau | 539 |
| Sleeping Bear Dunes National Lakeshore | 514 |
| Cabrillo National Monument | 500 |
| Casa Grande Ruins National Monument | 466 |
| Organ Pipe Cactus National Monument | 466 |
| Wright Brothers National Memorial | 464 |
| Little Rock Central High School NHS | 462 |
| Everglades National Park | 459 |
| Big Thicket National Preserve | 436 |
| Castillo de San Marcos National Monument | 404 |
| Hawaii Volcanoes National Park | 396 |
| Olympic National Park | 389 |
| Capulin Volcano National Monument | 342 |
| Canyonlands National Park | 339 |
| Carlsbad Caverns National Park | 335 |
| Tonto National Monument | 333 |
| Bents Old Fort Historic Site | 330 |
| Big South Fork National River & Recreation Area | 314 |
| Dinosaur National Monument (Passes only sold at UT location)) | 306 |
| Shenandoah National Park - Thornton Gap Entrance | 285 |
| Badlands National Park | 268 |
| Shenandoah National Park - Front Royal Entrance | 265 |
| Gila Cliff Dwellings National Monument | 257 |
| Mesa Verde National Park | 245 |
| Ulysses S Grant National Historic Site | 229 |

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|---|---|
| Grand Teton National Park | 229 |
| Saguaro National Park | 227 |
| Florissant Fossil Beds National Monument | 221 |
| Guadalupe Mountains National Park | 209 |
| Hot Springs National Park | 209 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Chickamauga & Chattanooga National Military Park | 203 |
| Crater Lake National Park | 196 |
| Shenandoah National Park - Swift Run Entrance | 195 |
| Obed Wild and Scenic River | 192 |
| Fort Washington Park | 179 |
| Glacier National Park | 175 |
| Big Bend National Park | 161 |
| Fossil Butte National Monument | 161 |
| White Sands National Monument | 158 |
| Haleakala National Park | 144 |
| Golden Spike National Historic Site | 144 |
| Weir Farm National Historic Site | 143 |
| Lava Beds National Monument | 134 |
| Delaware Water Gap National Rec Area | 133 |
| Mammoth Cave National Park | 130 |
| Bighorn Canyon National Recreation Area | 128 |
| Great Sand Dunes National Park | 124 |
| Fort Smith National Historic Site | 122 |
| Jewel Cave National Monument | 120 |
| Lassen Volcanic National Park | 114 |
| Gulf Islands National Seashore | 107 |
| Aztec Ruins National Monument | 101 |
| Greenbelt Park | 98 |
| Edison National Historical Park | 98 |
| Bandalier National Monument | 94 |
| Capitol Reef National Park | 93 |
| Saint Gaudens National Historic Site | 87 |
| Antietam National Battlefield | 85 |
| Prince William Forest Park | 84 |
| Shenandoah National Park - Rockfish Entrance | 84 |
| Sunset Crater Volcano National Monument | 82 |
| Chaco Culture National Historical Park | 78 |
| Craters of the Moon National Monument | 76 |
| Devils Tower National Monument | 73 |
| Canaveral National Seashore | 73 |
| Whiskeytown National Recreation Area | 71 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| William Howard Taft National Historical Site | 60 |
| Klondike Gold Rush National Historical Park | 60 |

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|---|---|
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Point Reyes National Seashore | 50 |
| Steamtown National Historic Site | 48 |
| Glen Canyon NRA | 44 |
| Wind Cave National Park | 40 |
| Timpanogos Cave National Monument | 36 |
| Padre Island National Seashore | 36 |
| Cape Cod National Seashore - Salt Pond V.C. | 35 |
| Fort Union National Monument | 35 |
| Mount Rushmore National Memorial | 35 |
| Fort Moultrie National Monument | 33 |
| Scotts Bluff National Monument | 27 |
| Fort Davis National Historic Site | 27 |
| Wilson's Creek National Battlefield | 26 |
| Vicksburg National Military Park | 26 |
| Lincoln Boyhood National Memorial | 22 |
| Little Bighorn Battlefield National Monument | 20 |
| Saratoga National Historical Park | 20 |
| Theodore Roosevelt National Park - South Unit | 20 |
| Denali National Park & Preserve | 19 |
| Pipestone National Monument | 19 |
| Harry S Truman National Historic Site | 19 |
| Tuzigoot National Monument | 18 |
| Pipe Spring National Monument | 18 |
| Mississippi National River & Recreation Area | 14 |
| Great Smoky Mountains NP - Sugarland VC | 12 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 12 |
| Great Basin National Park | 11 |
| Great Smoky Mountains NP - Oconaluftee Visitor's Center | 10 |
| Wupatki National Monument | 7 |
| Natural Bridges National Monument | 7 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| National Historic Oregon Trail Interpretive Center | 6 |
| Chickasaw National Recreation Area | 6 |
| Herbert Hoover National Historical Site | 5 |
| Fort Necessity National Battlefield | 4 |
| Johnstown Flood National Memorial | 4 |
| Carl Sandburg Home National Historic Site | 3 |
| Great Smoky Mountain NP - Cades Cove Campground | 3 |
| Valles Caldera National Preserve | 3 |
| Great Smoky Mountains NP - Smokemont Campground | 3 |
| Isle Royale National Park | 2 |
| Kings Mountain National Military Park | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Homestead National Monument of America | 2 |

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| Marsh-Billings-Rockefeller National Historical Park | 1 |
| **USACE** | **6,303** |
| Philpott Lake | 1,349 |
| Mississippi River Project | 900 |
| Allatoona | 730 |
| Falls Lake | 437 |
| Wappapello Lake | 385 |
| Table Rock Lake | 332 |
| Lake Shelbyville | 291 |
| Proctor lake | 261 |
| Englebright Lake | 195 |
| Sandy Lake Recreation Area | 191 |
| Carters | 175 |
| Gull Lake Recreation Area | 157 |
| Woodruff-Seminole | 150 |
| Raystown Lake Project | 144 |
| John H. Kerr Dam and Reservoir | 112 |
| Willamette Valley Project (Cottage Grove/Dorena) | 77 |
| Sam Rayburn Lake | 61 |
| Greers Ferry Lake | 60 |
| Cordell Hull Lake | 57 |
| Eastman Lake | 50 |
| Thurmond Project | 50 |
| Cochiti Lake | 49 |
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Jordan Lake | 10 |
| West Hill Dam | 4 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| North Hartland Lake | 2 |
| Tioga-Hammond Lakes Project | 1 |
| Success Lake | 1 |
| Barren River Lake | 1 |
| Cowanesque Lake Project | 1 |
| Hensley Lake | 1 |
| Abiquiu Lake | 1 |
| Bay Model Visitor Center | 1 |
| Coralville Lake | 1 |

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**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**Cc:** Rae, Kerry[kerry_rae@ios.doi.gov]; Marrone, Dean[dmarrone@usbr.gov]
**From:** Erath, Amanda
**Sent:** 2017-05-03T13:37:26-04:00
**Importance:** Normal
**Subject:** Re: Klamath River Basin Study
**Received:** 2017-05-03T13:40:02-04:00
Klamath Basin Study Appendices.docx

Thank you, Gok. I have attached the technical appendices that go with the Summary Report. If you can suggest a few time slots next week that would work for you I will get a call set up.

***Amanda Erath***
*Program Analyst*
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

*Office*: (303) 445-2766
*Email*: aerath@usbr.gov

On Wed, May 3, 2017 at 7:15 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Attached are the questions and comments I have so far, based on my current understanding of the study.
Why don't you look these over and we can schedule a call to discuss them. After you have educated me a little on the study and your approach, some of these issues may just go away, or I may have other questions.

Thanks.
Goks

On Wed, May 3, 2017 at 8:32 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Thanks Amanda.
I'll send you the questions that have occurred to me so far going through the summary report. My first question is: Is there a more detailed report (or set of reports) that this is a summary of? Regardless, I would suggest that after I send them to you (sometime this morning), you look these over and we can talk about them. Some/many of them might be disposed of that way. Others might require more elaboration and, if necessary, written responses.

Would this work for you?

Regards,
Goks

On Tue, May 2, 2017 at 6:25 PM, Erath, Amanda <aerath@usbr.gov> wrote:

That sounds good to me. Hi, Goks. If you would like to send me your questions I can work with folks to get you written answers, or if you prefer I can set up a call and we can get everyone on the line to try and answer your questions that way. Just let me know what you prefer.
Amanda

***Amanda Erath***
*Program Analyst*
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

*Office*: (303) 445-2766
*Email*: aerath@usbr.gov

On Tue, May 2, 2017 at 4:09 PM, Rae, Kerry <kerry_rae@ios.doi.gov> wrote:

Hi -
Amanda and Goks, I'm connecting you with regard to the Klamath River Basin Study. Goks has been asked to help with a Departmental review, and has some questions.

I figured we should start with you, Amanda, and you can help point to the appropriate technical points of contact for this Study based on Goks' questions.

Thanks!  Kerry

Kerry Rae
Chief of Staff for Water & Science
U.S. Department of the Interior
Phone: 202-513-0535
Mobile: 202-494-4101
Email: Kerry_Rae@ios.doi.gov

# Appendices

# Klamath River Basin Study

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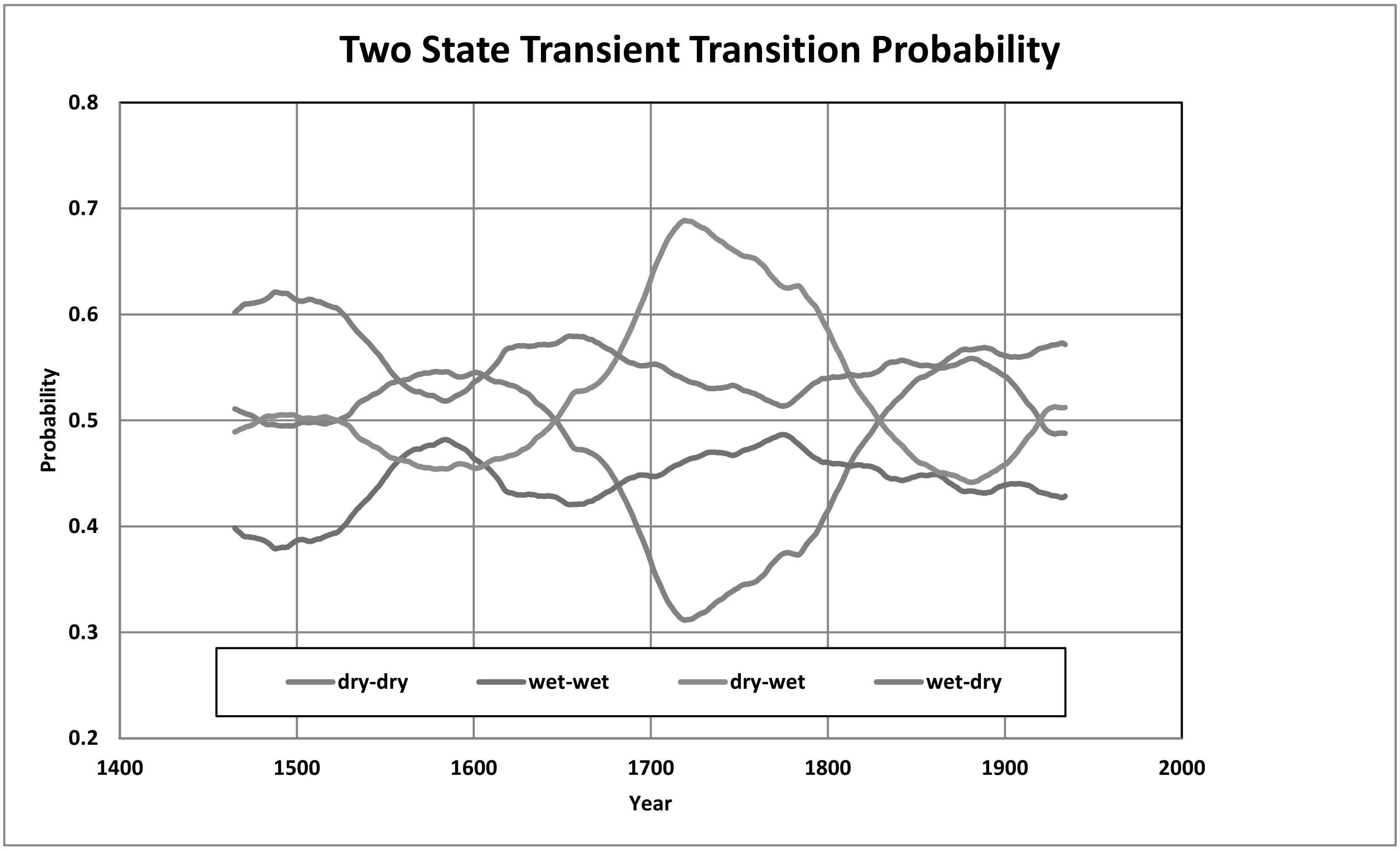
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**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**From:** Raff, David
**Sent:** 2017-05-04T12:50:18-04:00
**Importance:** Normal
**Subject:** Re: link
**Received:** 2017-05-04T12:50:37-04:00
hess-18-915-2014.pdf
jhm-d-14-0104.1.pdf
PNAS-2009-Pierce-8441-6.pdf
Gutmann_et_al-2014-Water_Resources_Research.pdf
Brekke.pdf
BrekkeEtAl2008.pdf
Moteetal2011.pdf

Here are just a couple additional resources:

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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

On Thu, May 4, 2017 at 10:35 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Normally I would say,"looking forward to it," but may be not this time!! ☺
> Cheers.

On Thu, May 4, 2017 at 12:31 PM, Raff, David <draff@usbr.gov> wrote:

> you as well - be looking for a series of additional emails with background materials for your consideration.

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

On Thu, May 4, 2017 at 10:29 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Thanks. Good to talk to you.

On Thu, May 4, 2017 at 11:49 AM, Raff, David <draff@usbr.gov> wrote:

> https://www.usbr.gov/watersmart/bsp/completed.html
> --
> David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

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# Significance of model credibility in estimating climate projection distributions for regional hydroclimatological risk assessments

**Levi D. Brekke · Michael D. Dettinger · Edwin P. Maurer · Michael Anderson**

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**Abstract** Ensembles of historical climate simulations and climate projections from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset were investigated to determine how model credibility affects apparent relative scenario likelihoods in regional risk assessments. Methods were developed and applied in a Northern California case study. An ensemble of 59 twentieth century climate simulations from 17 WCRP CMIP3 models was analyzed to evaluate relative model credibility associated with a 75-member projection ensemble from the same 17 models. Credibility was assessed based on how models realistically reproduced selected statistics of historical climate relevant to California climatology. Metrics of this credibility were used to derive relative model weights leading to weight-threshold culling of models contributing to the projection ensemble. Density functions were then estimated for two projected quantities (temperature and precipitation), with and without considering credibility-based ensemble reductions. An analysis for Northern California showed that, while some models seem more capable at recreating limited aspects twentieth century climate, the overall tendency is for comparable model performance when several credibility measures are combined. Use of these metrics to decide which models to include in density function development led to local adjustments to function shapes, but led to limited affect

L. D. Brekke (✉)
Technical Service Center 86-68520, U.S. Bureau of Reclamation, Denver, CO 80225-0007, USA
e-mail: lbrekke@do.usbr.gov

M. D. Dettinger
U.S. Geological Survey and Scripps Institution of Oceanography, La Jolla, CA 92093-0224, USA
e-mail: mddettin@usgs.gov

E. P. Maurer
Civil Engineering Department, Santa Clara University, Santa Clara, CA 95053-0563, USA
e-mail: emaurer@engr.scu.edu

M. Anderson
Division of Flood Management, California Department of Water Resources, Sacramento, CA 95821-9000, USA
e-mail: manderso@water.ca.gov

on breadth and central tendency, which were found to be more influenced by "completeness" of the original ensemble in terms of models and emissions pathways.

## 1 Introduction

Resource managers currently face many questions related to potential climate changes, in particular how climate may change and what regional impacts would ensue. One of the most pressing questions is whether contemporary resource-management decisions might increase or decrease future impacts. To address these questions, analysts typically compile global climate projections and then spatially downscale them for impacts assessment at regional scales relevant to a given decision. Given that there are more than 20 global climate models currently in operation, producing simulations of future climate under several different greenhouse gas (GHG) emission scenarios (Meehl et al. 2005), it is not surprising that results drawn from such impacts assessments depend on the particular GHG forcing scenarios and climate models present in these compilations.

Focusing on a few projected scenarios (e.g., bookend analyses) can lead to significant divergence among the projected future impacts. While such analyses are useful for illustrating what may be at stake under different future scenarios, they provide limited guidance for management responses in the present (e.g., Brekke et al. 2004; Cayan et al. 2006; Hayhoe et al. 2004; Vicuna et al. 2007). Rather, it is important for managers to understand the distributed and consensus nature of projected climate change impacts (Dettinger 2005; Maurer 2007) so that managers can begin to consider the relative likelihood of future impacts rather than just isolated examples of potential impacts. In line with this philosophy, there has been a trend in recent impacts assessments to base the studies on larger multi-model projection ensembles, as for instance in recent studies of potential hydrologic impacts in California's Central Valley (Maurer and Duffy 2005; Maurer 2007), the Colorado River Basin (Milly et al. 2005; Christensen and Lettenmaier 2006), and in other locations (Wilby and Harris 2006; Zierl and Bugmann 2005).

Expanding regional impacts analyses to consider larger climate projection ensembles creates the opportunity to address and communicate impacts in the terms of risks rather than isolated examples of possible impacts. The difference between risk and impact assessments is that risk goes beyond scenario definition and analysis of associated impacts to also address relative scenario likelihoods. Framing regional assessments in terms of risk is attractive from a management perspective because risk information is better suited for strategic planning, where responses can be formulated based upon weighted prospects of different impacts. This approach helps to guide the timely use of limited available funds that might support responses to inherently uncertain future conditions.

The product of a risk analysis is a presentation of distributed impacts from a collection of scenarios weighted by their estimated likelihoods. In the climate change context, *absolute* scenario likelihoods cannot be identified. However, *relative-* or *consensus-based* likelihoods of various scenarios can be estimated from an ensemble of climate projections by fitting a climate projection density function. Granted, such density functions only represent a limited portion of the climate change uncertainties, because elements such as social and physical factors affecting global GHG sources and sinks in the future, climate response and interactions with these GHG sources and sinks, and alternative climate model structures are not included. However, the ensemble density functions provide a more complete basis for using and interpreting the elements of the available ensembles than is afforded by scenario analyses without such context. Using projection density functions to

infer relative scenario likelihoods promotes strategic response planning, framed by perception of which outcomes are – at present – projected to be more likely among projected possibilities, which is a step forward from not considering scenario likelihoods at all.

Several methods for generating climate projections density functions have been proposed (Tebaldi et al. 2005; Dettinger 2006). The ensembles employed can include several greenhouse gas emission pathways, multiple climate models, and multiple "runs" of a given pathway-model combination differing by initial conditions. In applying these methodologies, it is natural to ask whether all members from a projection ensemble should be valued equally. Put another way, there are more than 20 coupled atmosphere–ocean climate models informing the last assessment from IPCC (2007): in the context of regional response analysis, are the projections from all of these models equally credible?

This latter thought motivates the two questions considered in this paper: (1) How does apparent model credibility at a regional scale, translated into relative model weighting and subsequent model culling, affect estimates of climate projection density functions?, and (2) How are relative scenario likelihoods, derived from the density function, affected when model credibility is considered when estimating the function?

To explore the first question, a philosophy is adopted that relative model credibility in projecting twenty-first century climate can be estimated from relative model accuracy in simulating twentieth century climate. Some studies have found little effect of weighting future climate projections by perceived differences between model completeness (e.g., Dettinger 2005, weighted models based on whether they required "flux corrections" or not to avoid climate drift and found little difference in estimated density functions). However, several interpretations of projection ensembles have been designed around the concept of weighting results by perceived historical accuracies (AchutaRao and Sperber 2002, 2006; Bader et al. 2004; Phillips et al. 2006). Following this approach, a procedure is developed here, beginning with a model credibility analysis to produce relative model credibility indices, as a basis for model culling, followed by a nonparametric procedure for estimating climate projection density functions, with and without consideration of model credibility results.

In the latter step, an "Uncertainty Ensemble" of climate projections is used to fit the density functions. In relation to the second question, a *subset* of the Uncertainty Ensemble is identified (i.e. Impacts Ensemble) for which relative scenario weights are derived from the density functions fit with and without consideration of model credibility. The nested nature of this Impacts Ensemble within the Uncertainty Ensemble represents a typical situation in regional risk assessment where the feasible size of an Impacts Ensemble (i.e. scenarios studied in detail for impacts in multiple resource areas) is less than what can be considered when fitting the climate projection density function because of the computational intensity of the impact calculations. The remainder of this paper presents the methodologies for model credibility and climate projection density analyses (section 2), results from applying these methods to a particular region (i.e. California's Central Valley) where the concern is water resources impacts (section 3), a discussion of method limitations and areas of potential improvement (section 4), and a summary of major conclusions (section 5).

## 2 Methodology

The analytical sequence features two primary parts. The first part involves a model credibility analysis based on how well selected parts of the historical climate are simulated by the various models, and includes the following steps: (1) choosing relevant climate

variables and reference data, (2) choosing performance metrics and computing measures of model-to-observation similarities, and (3) deriving weights and culled model groups based on these measures. The second part is an analysis of climate projections where projection density functions are fit with and without consideration of results from the model credibility analysis.

The analyses are based on simulated climate variables from coupled atmosphere–ocean general circulation models (i.e. WCRP CMIP3 models) used to produce (a) twenty-first century climate projections under both SRES A2 and B1 emissions pathways (IPCC 2001) and (b) simulations for the "climate of the twentieth century experiment (20C3M)," conducted by CMIP3 participants (Covey et al. 2003). The Lawrence Livermore National Laboratory's Program for Climate Model Diagnosis and Intercomparison (PCMDI) hosts a multi-model archive for 20C3M historical simulations, twenty-first century projections, and other scenario and control run datasets. Among the models producing 20C3M simulations, the number of available "runs" varied per model, with runs differing by initialization decisions. An attempt was made to focus on models that had simulated both A2 and B1 on the grounds that these pathways represent a broad and balanced range of SRES possibilities (IPCC 2001). However, this criterion was relaxed for two of the selected models from which only A2 or B1 simulations were available.

In total, 17 climate models were represented in our survey (Table 1). Collectively they were used to produce 59 20C3M simulations (used for the model credibility analysis) and 75 climate projections comprised of 37 SRES A2 simulations and 38 SRES B1 simulations. The set of 75 climate projections served as the Uncertainty Ensemble, mentioned in section 1, and was used in climate projection density analysis. From the Uncertainty Ensemble, *subsets* of 11 SRES A2 and 11 SRES B1 projections were identified as a 22-member Impacts Ensemble (Table 1). The selected 22 projections are the same projections considered in a previous study on potential hydrologic impacts uncertainty within the Sierra Nevada (Maurer 2007).

### 2.1 Credibility analysis: choosing simulated and references climate variables

The first step in the model credibility analysis involved choosing simulated climate variables relevant to the geographic region of interest (i.e. Northern California in this case study), and identifying climate reference data to which simulated historical climates could be compared (i.e. 20C3M results listed in Table 1). Three types of variables were used: local variables that define Northern California climatology, distant variables that characterize global-scale climatic processes, and variables that describe how global processes relate to the local climatology (i.e. teleconnections). This mix was chosen because the first interest for this regional scale assessment was how the local climate variables might change in the future. However, in the projections considered here, those changes are driven and established by global scale forcings (GHGs) and resulting processes. Thus, both local and global performances are important. Furthermore, the connection between global and local processes must be accurately recreated in the models (indicated by either the presence or absence of significant inter-variable correlation, i.e. teleconnections) in order for their simulated local responses to global forcings to be considered reliable.

Two local variables were used to describe the regional climatology: surface air temperature and precipitation conditions (i.e. NorCalT and NorCalP near {122W, 40N}). Global-scale phenomena driving the regional climatology via teleconnections include pressure conditions over the North Pacific (related to mid-latitude storm track activity upwind of North America) and the phase of the El Niño Southern Oscillation (ENSO;

**Table 1** Climate projections and models included in this case study

| WCRP CMIP3 model I.D.[a] | Model abbreviation in this study | Model number | Projection run numbers[b] | | | | 20C3m Ensemble |
|---|---|---|---|---|---|---|---|
| | | | Uncertainty | | Impacts | | |
| | | | A2 | B1 | A2 | B1 | |
| CGCM3.1(T47) | cccma_cgcm31 | 1 | 1…5 | 1…5 | | | 1…5 |
| CNRM-CM3 | cnrm_cm3 | 2 | 1 | 1 | 1 | 1 | 1 |
| CSIRO-Mk3.0 | csiro_mk30 | 3 | 1 | 1 | 1 | 1 | 1…3 |
| GFDL-CM2.0 | gfdl_cm20 | 4 | 1 | 1 | 1 | 1 | 1…3 |
| GFDL-CM2.1 | gfdl_cm21 | 5 | 1 | 1 | | | 1…3 |
| GISS-ER | giss_model_er | 6 | 1 | 1 | 1 | 1 | 1…9 |
| INM-CM3.0 | inmcm3_0 | 7 | 1 | 1 | 1 | 1 | 1 |
| IPSL-CM4 | ipsl_cm4 | 8 | 1 | 1 | 1 | 1 | 1 |
| MIROC3.2(hires) | miroc32_hires | 9 | | 1 | | | 1 |
| MIROC3.2(medres) | miroc32_medres | 10 | 1…3 | 1…3 | 1 | 1 | 1…3 |
| ECHAM5/MPI-OM | mpi_echam5 | 11 | 1…3 | 1…3 | 1 | 1 | 1…3 |
| MRI-CGCM2.3.2 | mri_cgcm232a | 12 | 1…5 | 1…5 | 1 | 1 | 1…5 |
| CCSM3 | ncar_ccsm30 | 13 | 1…5 | 1…8 | | | 1…8 |
| PCM | ncar_pcm1 | 14 | 1…4 | 2…3 | 1 | 2 | 1…4 |
| UKMO-HadCM3 | ukmo_hadcm3 | 15 | 1 | 1 | 1 | 1 | 1…2 |
| UKMO-HadGEM1 | ukmo_hadgem1 | 16 | 1 | | | | 1…2 |
| ECHO-G | miub echo-g | 17 | 1…3 | 1…3 | | | 1…5 |
| Total Runs | | | 37 | 38 | 11 | 11 | 59 |

[a] From information at Lawrence Livermore National Laboratory's Program for Climate Model Diagnosis and Intercomparison (PCMDI), September 2006: http://www-pcmdi.llnl.gov

[b] Run numbers assigned to model- and pathway-specific SRES projections and model-specific 20c3m simulations in the WCRP CMIP3 multi-model data archive at PCMDI.

affecting Pacific-region interannual climate variability and beyond). Two measures of these phenomena were used in this study, respectively: the North Pacific Index (NPI), describing mean sea level pressure within {30N–65N, 160E–140W} and the Nino3 Index describing ENSO-related mean sea surface temperature within {5S–5N, 150W–90W}.

Monthly time series of each evaluation variable were extracted from each 20C3M simulation for the latter half of the twentieth century (1950–1999). Likewise, monthly 1950–1999 "reference" data were also obtained. For NPI, NorCalP, and NorCalT, the reference data were extracted from the NCEP Reanalysis (Kalnay et al. 1996, updated and provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/), which is a data set of historical observations modified and interpolated with the use of an atmospheric climate model and which describes climate conditions at roughly the same scale as the coupled climate models used in the historical simulations. The reference data for Nino3 were obtained from the Monthly Atmospheric and SST Indices archive provided by the NWS Climate Prediction Center, Camp Springs, Maryland, USA, from their Web site at http://www.cpc.noaa.gov/data/indices/.

Simulated and reference time series were compared during the 1950–1999 period. It is arguable whether this 50-year historical period should be shorter and more recent. The decision to consider 1950–1999 as opposed to a shorter period was driven by recognition that 20C3M simulations express interdecadal variability that might be out of phase with that

observed during the twentieth century, leading to exaggerated simulation-reference differences or similarities based solely on choice of sampling overlap period.

## 2.2 Credibility analysis: choosing performance metrics and teleconnections

The next step was to choose performance metrics that describe statistical aspects of the local and global variables and their teleconnections. For each variable, a set of six metrics was evaluated (Table 2): the first three statistical moments of annual conditions (mean, variance, skewness), an interdecadal variance describing lower frequency variability (Table 2, note 4), amplitude of seasonality defined by the range of mean monthlies, and phase of seasonality defined by correlation between simulated and reference mean monthlies. For the local variables (i.e. NorCalT and NorCalP), the characteristics of extreme positive anomalies were considered (i.e. the annual maximum monthly value exceeded in 10% of years). Seasonal correlations (teleconnections) between the two local and two global variables were considered, as well as seasonal and annual correlations between the two global variables. For NorCalT, the 50-year trend was used as an additional variable-specific metric. For NorCalP, a metric of drought recurrence and severity was also included and framed by knowledge of relevant 1950–1999 droughts in the case study region. Because the most significant sustained drought in the Northern California instrumental record was about 6 years in duration (1987–1992), the drought metric was defined as the running 6-year precipitation total exceeded by 90% of the 6-year spells within each 50-year time series. Finally, as a measure of how temporally realistic the simulated ENSO processes were, and because local interannual variability is influenced by ENSO, a metric describing El Niño reoccurrence was defined as the spectral power of the 50-year Nino3 time series concentrated in the 2-to-7 year range.

This is a fairly extensive array of metrics, and it is difficult to know which of the metrics are most pertinent to the projection of future impacts of increasing GHGs. Application of this methodology thus will involve consideration of which metrics are the most relevant measures of model credibility. In applications of this approach to other regions, decisions to include other, or additional, metrics beyond those discussed herein should depend on the region and climate in question. Although no definitive statements can be made as to which metrics are the more relevant, it is reasonable to expect that different impacts assessment perspectives might gravitate toward different metrics. For illustration purposes, three perspectives are defined and used here to explore sensitivity of impressions to this question. The perspectives are loosely termed Water Supply, Hydropower, and Flood Control. For each perspective, the 49 metrics of Table 2 were reduced to six arbitrarily chosen metrics as being “more relevant.”

- For the Water Supply perspective, managers are assumed to have the ability to seasonally store precipitation-runoff and thus might be more concerned about how climate models reproduce the past precipitation in terms of long-term mean and seasonality phase, past temperature in terms of long-term trend and seasonality phase, multi-year drought severity, and global teleconnections relevant to the precipitation season (e.g., Nino3-NorCalP during Winter).
- For the Hydropower perspective, concerns were assumed to be similar to those of Water Supply (e.g., precipitation long-term mean, temperature long-term trend), but with more concern shifted to other types of global teleconnections with local climate (e.g., NPI correlation with NorCalP during autumn and winter) and on global interannual variability in general as it might affect hydro-energy resources from a larger

**Table 2** Variables and performance metrics used in this model credibility study

| Performance metrics | Metrics by climate variable, 1950–1999 monthly data, describing: [A] global, [B] local, [C] teleconnections | | | |
|---|---|---|---|---|
| | NPI[a] | NorCalP | NorCalT | Nino3 |
| Mean[b] | [A] | ***[B]***[n] | [B] | [A] |
| Variance[c] | [A] | *[B]* | [B] | [A] |
| Interdecadal variance[d] | [A] | [B] | [B] | [A] |
| Skewness[c] | [A] | [B] | [B] | [A] |
| Seasonality amplitude[e] | [A] | [B] | [B] | [A] |
| Seasonality phase[f] | [A] | **[B]** | **[B]** | [A] |
| 6-year mean, 90%exc[g] | | **[B]** | | |
| Annual maximum month, 10% exc[h] | | [B] | [B] | |
| Trend in annual mean (50-year) | | | ***[B]*** | |
| El Niño reoccurrence[i] | | | | *[A]* |
| Correlation with Nino3 during OND[j] | [C] | [C] | [C] | |
| Correlation with Nino3 during JFM | [C] | **[C]** | [C] | |
| Correlation with Nino3 during AMJ | [C] | [C] | [C] | |
| Correlation with Nino3 during JAS | [C] | [C] | [C] | |
| Correlation with NPI during OND | | *[C]* | [C] | |
| Correlation with NPI during JFM | | *[C]* | [C] | |
| Correlation with NPI during AMJ | | [C] | [C] | |
| Correlation with NPI during JAS | | [C] | [C] | |
| Correlation with Nino3, annually[k] | [C] | | | |

*OND* October through December, *JFM* January through March, *AMJ* April through June, *JAS* July through September

[a] NPI (North Pacific Index) is defined as monthly mean sea level pressure within (30N–65N, 160E–140W), Nino3 is defined as monthly mean sea surface temperature within (5S–5N,150W–90W), and NorCalP and NorCalT are monthly precipitation and surface air temperatures near 122W and 40N.

[b] Mean annual total for NorCalP; mean annual average for other variables.

[c] Computed on annual total or mean values (see note b).

[d] Computed on annual values smoothed by a 9-year moving average.

[e] Computed on monthly means, identifying the difference between maximum and minimum values.

[f] Computed as correlation between simulation and climate reference monthly means (see note l).

[g] 90% exceedence value in sorted series of running 6-year mean-annual values.

[h] 10% exceedence value in sorted series of annual maximum month values.

[i] Based on spectral analysis of the time series phase variability (see note m), identifying the average power in 2- to 7-year period band.

[j] Computed as correlation between seasonal mean conditions between the indicated variable pair (row and column; see abbreviations).

[k] Same as note j, but computed as correlation between annual mean conditions.

[l] Climate reference for NPI, NorCalP, and NorCalT from NCEP/NCAR Reanalysis monthly data products at NOAA Climate Diagnostic Center; Climate reference conditions for Nino3 from monthly index values at NOAA Climate Prediction Center.

[m] Processing involves removing monthly means, and then scaling total power by normalizing the mean-removed time series to unit variance.

[n] Metric Subsets: Water Supply (bold), Hydropower (italics), Flood Control (underline).

regional hydropower market encompassing the runoff region of interest (e.g., Nino3 El Niño reoccurrence).

– For the Flood Control perspective, more focus was assumed to be placed on how the climate models recreate more extreme aspects of precipitation climatology (e.g., precipitation skewness, seasonality amplitude, annual maximum month that is exceeded in 10% of the 50-year evaluation period).

Notably, historical simulations were not rated in terms of whether they reproduced precipitation trends of the past 50 years. As noted previously, the region in question is subject to large, significant and persistent multidecadal climate fluctuations historically, under the influence of multidecadal climate processes over the Pacific Ocean basin and beyond (e.g., Mantua et al. 1997; McCabe et al. 2004). Historically the multidecadal Pacific Ocean influence has resulted in significant and persistent climatological differences between the 1948–1976 period and the 1977–1999 period. Although these long-term differences may very well be mostly natural, random and reversible, they have imposed a trend-like character on the Northern California climate during 1950–1999. Even a skillful coupled ocean–atmosphere model, initiated much earlier in the nineteenth or twentieth centuries, would not be expected to reproduce the timing of such natural multidecadal fluctuations in a way that would reproduce the trend-like halving of the 1950–1999 window considered here. Thus the presence or absence of a regionalized precipitation trend in observations and apparent difference in historical simulated trend did not seem to be a good measure of the simulation skill in the particular study region considered here.

### 2.3 Credibility analysis: deriving model weights and model culling

After computing simulation metrics, run-specific calculations of simulated-minus-reference metric differences were pooled by model and averaged to produce 17 model-representative differences. A distance-based methodology was then used to measure overall model-to-reference similarities for each set of metrics. Under the distance-based philosophy, a distance is computed within a "similarity space" defined along "metric dimensions." For example, the similarity space could be a seven-dimensional space spanned by the seven NPI performance metrics, or a 49-dimensional space spanned by all performance metrics in Table 2. Given a space definition, distance can be computed using one of several distance formulas. Euclidean or Manhattan distance formulas were explored in this study (Black 2006), with focus ultimately placed on Euclidean distance. Results were found to be insensitive to choice of distance formula, primarily because metric differences were scaled to have unit variance across models for each metric, prior to distance calculation, so that metric differences generally all had magnitudes near or less than one. Such magnitudes aggregate into similar distances using the Euclidean and Manhattan formulas.

The purpose of scaling metric differences was to prevent metrics measured in large units from dominating the computed distance (e.g., the El Nino reoccurrence metric differences have values on the order of $10^3$ where as the seasonality and teleconnection correlation-metrics have differences on the order of $10^{-1}$ to $10^{-2}$). A disadvantage of scaling the metric differences is that it can exaggerate a metric's influence on model discrimination even though pre-scaled metric differences were quite similar (e.g., simulated NorCalT seasonality phase and difference from reference).

For a given set of metrics, the procedure results in computation of 17 model-representative distances from references. Relative model weights were then computed as the inverse of this distance. Finally, a threshold weight criterion was used to cull models from

consideration in the subsequent climate projection density analysis. The model-culling depends on the metric set used and the threshold model weight selected to differentiate between models that will be retained and those that will not. For illustration, in this study, the weight threshold was defined to be median among the 17 weights, so that the nine highest weighted models were retained from among the 17 considered.

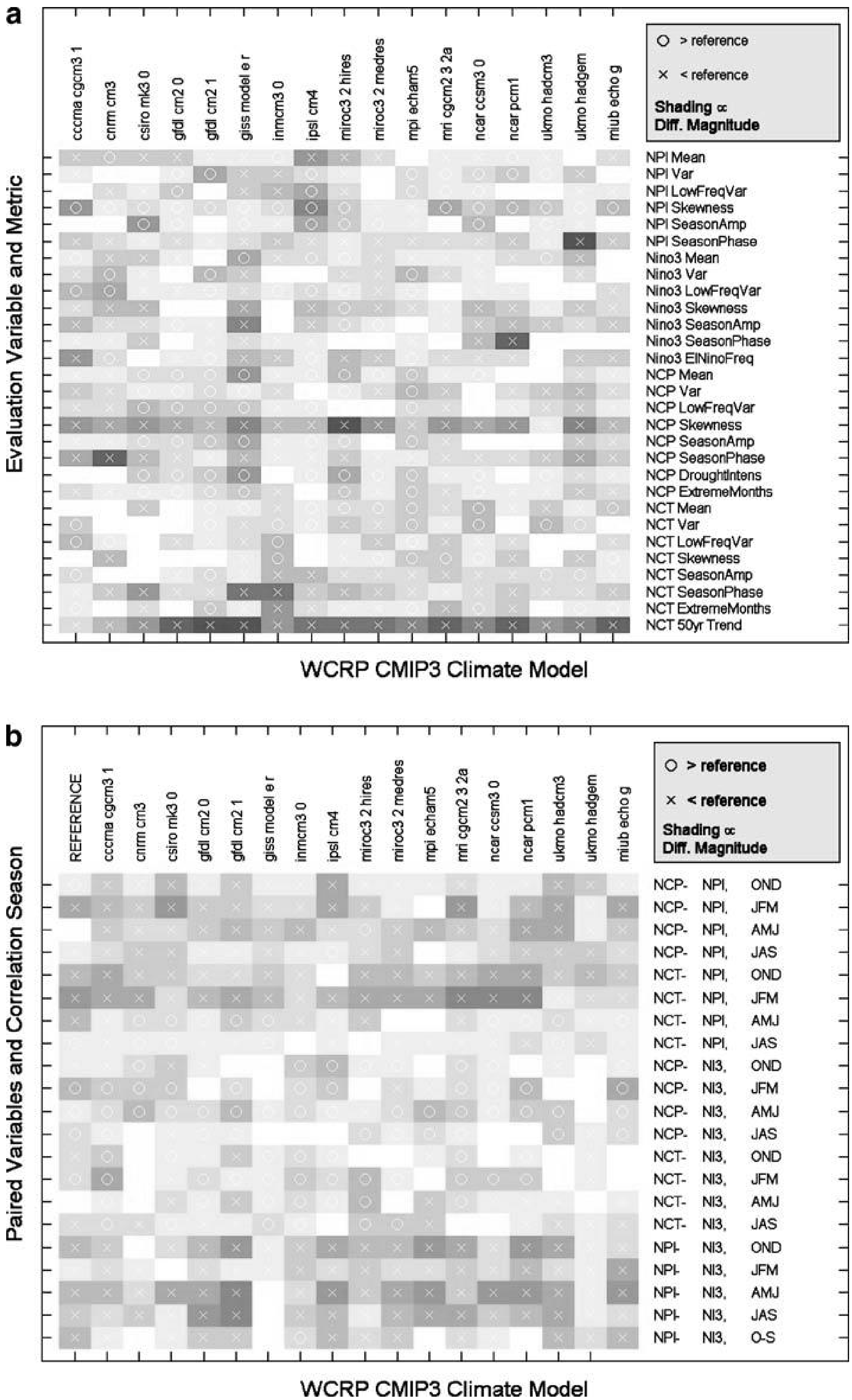
Looking ahead to the climate projection density analysis, the use of these credibiltiy analysis results could have involved proportional weighting of the models rather than culling of models. All models could have been retained and various methods to proportionally represent model contribution in the projection density functions could have been used. This alternate approach was explored, with density functions fit using nonparametric techniques (section 2.4). However, it led to excessively multi-modal, "peaky" density functions, set up by the interspersed positions of fitting data (i.e. specific projections) from "less credible" models and "more credible" models. and was abandoned for the culling-based approach used here.

## 2.4 Climate projection density analysis, with and without model credibility

Density functions were constructed for projected anomalies of 30-year average "annual total precipitation" and "annual mean surface air-temperature' [i.e. d($P$) and d($T$), respectively], evaluated for the 2010–2039 and 2040–2069 periods relative to a 1950–1999 base period. Several methodologies have been proposed for developing density functions that describe likelihoods of univariate or multivariate climate projections (Tebaldi et al. 2005; Dettinger 2006). An empirical procedure is used here, involving nonparametric density estimation using Gaussian kernels (Scott 1992; Wilks 1995) with optimized bandwidths (Silverman 1986). For the multivariate case of jointly projected anomalies of temperature and precipitation, a product-kernel extension of the univariate approach is used (Scott 1992)). Nonparametric density estimation has been applied in numerous statistical-hydrology studies (e.g., Lall et al. 1996; Piechota et al. 1998). It will be shown that very similar joint density functions are obtained by using another estimation approach (Dettinger 2006). The emphasis here is on the common motivation underlying these methods: to consolidate projection information into distributions that help focus planning attention on ensemble consensus rather than extremes (Dettinger 2006), and whether relative model credibility should be factored into this consolidation.

A key decision in estimating the density functions was how to deal with the various numbers of simulations available from a given pathway-model combination (e.g., model CCSM3 contributes eight SRES B1 simulations whereas model PCM contributes two). In the present study, all simulations from all contributing models have been treated as equals. Just as the culling approach used here could have been replaced with a weighting of all the models, this assignment of equal weights to all of the simulations could have been replaced by weightings of the contributions from various simulations that avoided overemphasis of simulations from the more prolific modeling groups. Such weightings were explored in this study and tended to yield results similar to the distributions shown herein, especially with respect to the central tendencies and spans of the density functions.

In applications of the product kernel for bivariate density estimation, relative variable scales and choices for variable-specific domain resolution and range can influence results. To account for this influence, each univariate function contributing to the product kernel was fit to anomalies scaled by their respective standard deviations. After constructing the bivariate density function from these scaled data, the function values relative to each scaled anomaly position were mapped back into their unscaled values.


a
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Shading ∝ Diff. Magnitude
cccma cgcm3 1
cnrm cm3
csiro mk3 0
gfdl cm2 0
gfdl cm2 1
giss model e r
inmcm3 0
ipsl cm4
miroc3 2 hires
miroc3 2 medres
mpi echam5
mri cgcm2 3 2a
ncar ccsm3 0
ncar pcm1
ukmo hadcm3
ukmo hadgem
miub echo g
NPI Mean
NPI Var
NPI LowFreqVar
NPI Skewness
NPI SeasonAmp
NPI SeasonPhase
Nino3 Mean
Nino3 Var
Nino3 LowFreqVar
Nino3 Skewness
Nino3 SeasonAmp
Nino3 SeasonPhase
Nino3 ElNinoFreq
NCP Mean
NCP Var
NCP LowFreqVar
NCP Skewness
NCP SeasonAmp
NCP SeasonPhase
NCP DroughtIntens
NCP ExtremeMonths
NCT Mean
NCT Var
NCT LowFreqVar
NCT Skewness
NCT SeasonAmp
NCT SeasonPhase
NCT ExtremeMonths
NCT 50yr Trend
Evaluation Variable and Metric
WCRP CMIP3 Climate Model
b
○ > reference
× < reference
Shading ∝ Diff. Magnitude
REFERENCE
cccma cgcm3 1
cnrm cm3
csiro mk3 0
gfdl cm2 0
gfdl cm2 1
giss model e r
inmcm3 0
ipsl cm4
miroc3 2 hires
miroc3 2 medres
mpi echam5
mri cgcm2 3 2a
ncar ccsm3 0
ncar pcm1
ukmo hadcm3
ukmo hadgem
miub echo g
NCP- NPI, OND
NCP- NPI, JFM
NCP- NPI, AMJ
NCP- NPI, JAS
NCT- NPI, OND
NCT- NPI, JFM
NCT- NPI, AMJ
NCT- NPI, JAS
NCP- NI3, OND
NCP- NI3, JFM
NCP- NI3, AMJ
NCP- NI3, JAS
NCT- NI3, OND
NCT- NI3, JFM
NCT- NI3, AMJ
NCT- NI3, JAS
NPI- NI3, OND
NPI- NI3, JFM
NPI- NI3, AMJ
NPI- NI3, JAS
NPI- NI3, O-S
Paired Variables and Correlation Season
WCRP CMIP3 Climate Model

◀ **Fig. 1** **a** Scaled model-specific average difference between multiple 20c3m run results and Reference for metric types [A] and [B] in Table 2. Scaling involves pooling run- and metric-specific differences across models and scaling collectively to unit variance. *Shading* shows magnitude of scaled difference, with *darker shading* showing greater magnitude of difference. "*X*" and "*O*" symbols are used to indicate the sign of difference from reference. **b** Similar to **a**, but for metric type [C] in Table 2

## 3 Case study results – Northern California

### 3.1 Credibility analysis

As mentioned in section 2, the case study region for this study was Northern California, leading to the focus on two relevant local climate variables for credibility analysis (NorCalP and NorCalT), two global variables influential on local variables (NPI and Nino3), and respective global–local teleconnections. Summaries of scaled, model-representative, metric differences between simulated 20C3M results and observational references are shown on Fig. 1a and b. The figures qualitatively indicate relative differences among models for each metric. They do not indicate *specific* differences for a given model and metric. For example, consider differences between each models's average-20C3M NPI Mean and Reference NPI Mean (Fig. 1a, top row). The figure shows shading that scales from light to dark as the *magnitude of a difference* increases; the *sign* of the difference is indicated by "x" for negative and "o" for positive. Results suggest that "mpi echam5" and "ukmo hadgem" generally did a better job reproducing Reference NPI Mean. As another example, consider the bottom row of Fig. 1a, which shows that the models consistently underpredicted the Reference trend in NorCalT during 1950–1999. However, what isn't shown on Fig. 1a (because specific differences are not shown) is that all models correctly simulated a *warming* trend, just not enough warming compared to Reference.

Figure 2 indicates relative model weights derived for each model based on the metric values indicated in Table 2 (i.e. All Variables and Metrics, and metric sets related to the Water Supply, Hydropower, and Flood Control perspectives). The latter three sets were defined and discussed in section 2.2. For the "All Variables and Metrics" case, which incorporated all 49 metrics in Table 2, the relative model weight varies among models by roughly a factor two. Projections from the "gfdl cm2 0," "miroc3 2 medres," and "ncar ccsm3 0" models would be granted more credibility in this context (Fig. 2). For the "gfdl cm2 0" and "miroc 3 2 medres" models, their greater weights stem from scoring well in multiple variable-specific subsets. The greater weight for the "ncar ccsm3 0" model was obtained more by scoring well in the NorCalP subset. For the three perspectives, which focused on considerably fewer metrics, the range of relative model weights grows to a factor of 3 to 4.

Retaining models having weight greater than or equal to the median weight among the 17 model-specific values, Table 3 shows groups of retained models based on each set of model weights from Fig. 2. The mix of retained models differs depending on which variables were used to decide credibility. This is particularly the case if credibility is determined by fewer simulation metrics. The ensemble of coupled climate models providing projections includes fairly wide ranges of credibility when individual metrics are considered, but have more similar credibility when the intercomparison is made across a suite of simulated variables. That is, generally, a model may do very well on one metric but not another, and overall these differences average out for most model-to-model comparisons when several dozen metrics are brought to bear.

The effect on deciding model retention of various choices of metric sets was explored, with a subset of results illustrated on Fig. 3, which shows how model retention varies for

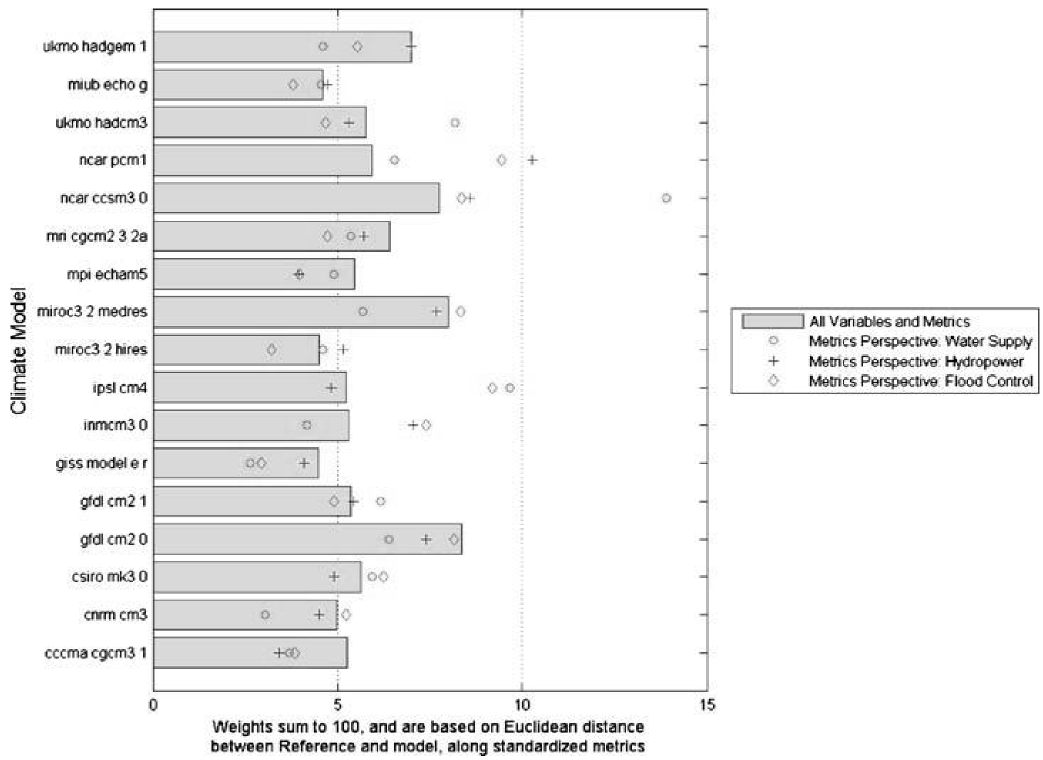


**Fig. 2** Model Weights computed based on different metric sets (see Table 3). For a given metric set, model weights are scaled collectively to sum to 100

each of the combinatorial possibilities of one- to eight-metric sets from the type [B] metrics associated with NorCalP (Table 2). Results show that, while model retention varies with the metric set used, some models would be more frequently retained and thus are could be considered to be the relatively more credible models for simulating NorCalP (e.g., “ukmo hadgem1,” “ncar pcm,” “ncar ccsm3 0,” “miroc3 2 medres,” “ipsl cm4,” “inmcm3 0,” and “gfdl 2 0”). Next generation models (e.g., “gfdl cm 2 1” compared to “gfdl cm 2 0”) and higher resolution models (e.g., “miroc3 2 hires” compared to “miroc3 2 medres”) do not necessarily fare better than their predecessors in such credibility evaluations.

## 3.2 Climate projection density functions

The results from Table 3 were carried forward to the construction of climate projection density functions. Prior to fitting density functions, ensembles of projected time series (Table 1) for surface air temperature and precipitation anomalies, as simulated near {122W, 40N}, were extracted from the A2 and B1 simulations retained in the previous step. Anomalies were computed as deviations of the projected monthly values from the model’s 1950–1999 20C3M monthly means. Projected anomalies were then bias-corrected to account for model tendencies relative to observations on the projected quantities (i.e. NorCalP and NorCalT from Reanalysis). Bias-correction was performed on a month-specific basis by multiplying projected anomalies by the ratio of Reanalysis monthly means to the model’s 20C3M monthly means. After bias-correction, monthly anomalies were consolidated into annual mean surface air temperature anomalies and annual total precipitation anomalies for each the 75 projections (Fig. 4).

**Table 3** Model membership in projection ensemble after culling by model credibility using different metric sets[a,b]

| WCRP CMIP3 Model I.D.[c] | Metric Set[b] | | | |
|---|---|---|---|---|
| | All variables and metrics | Water supply metrics | Hydropower metrics | Flood control metrics |
| CGCM3.1(T47) | | | | |
| CNRM-CM3 | | | | x |
| CSIRO-Mk3.0 | x | x | | x |
| GFDL-CM2.0 | x | x | x | x |
| GFDL-CM2.1 | | x | x | |
| GISS-ER | | | | |
| INM-CM3.0 | | | x | x |
| IPSL-CM4 | | x | | x |
| MIROC3.2(hires) | | | | |
| MIROC3.2(medres) | x | x | x | x |
| ECHAM5/MPI-OM | x | | | |
| MRI-CGCM2.3.2 | x | x | x | |
| CCSM3 | x | x | x | x |
| PCM | x | x | x | x |
| UKMO-HadCM3 | x | x | x | |
| UKMO-HadGEM1 | | | | |
| ECHO-G | x | | x | x |

[a] Based on evaluation of models' 20c3m Euclidean similarity to Reference (Table 2, note l).

[b] First column considers all variables and metrics from Table 2. Remaining three columns consider six metrics chosen as relevant to three impacts perspectives (Table 2, note n).

[c] WCRP CMIP3 Model I.D. explained in Table 1, note a.

Each time series of projected annual anomalies was averaged over the periods 2010–2039 and 2040–2069, leading to two 75-member pools of projected "30-year mean" anomalies (i.e. projected "climatological" anomalies) for density function fitting. Density functions for projected climatological temperature anomalies [d($T$)] and precipitation anomalies [d($P$)] are shown on Fig. 5a and b, respectively. Density functions were constructed for each projected quantity and period for five cases: "No Model Culling," meaning that functions were fit to all 75 projections listed in Table 1, and the four basis metric sets used for model culling (Table 3, columns 2–5). Anomaly positions of the 22-member Impacts Ensemble (sections 1 and 2) are also shown on the horizontal axes of each figure. Density functions for jointly projected climatological anomalies for temperature and precipitation [d($T$,$P$)] are shown on Fig. 6a and b, for the 2040–2069 period only and respectively for the "No Model Culling" and "Cull Basis: Water Supply" (Table 3, column 3). Also shown on Fig. 6a and b are two density surfaces, one estimated using product kernel technique described in section 2, and another using a second estimation method described by Dettinger (2006). The similarity of the estimated surfaces suggests that choice of estimation methods is not crucial here.

Focusing on how d($T$) varies with the choice of retained models, it is clear that the choice of models led to some changes in density magnitudes within the functions. However, comparison of the functions for the non-culled and culled cases shows that the general spread and central tendencies of the density functions are not drastically affected by the how model credibility assessment was used to cull models. Moreover, the positions of the dominant modes are generally consistent. It seems that the 75-member ensemble of

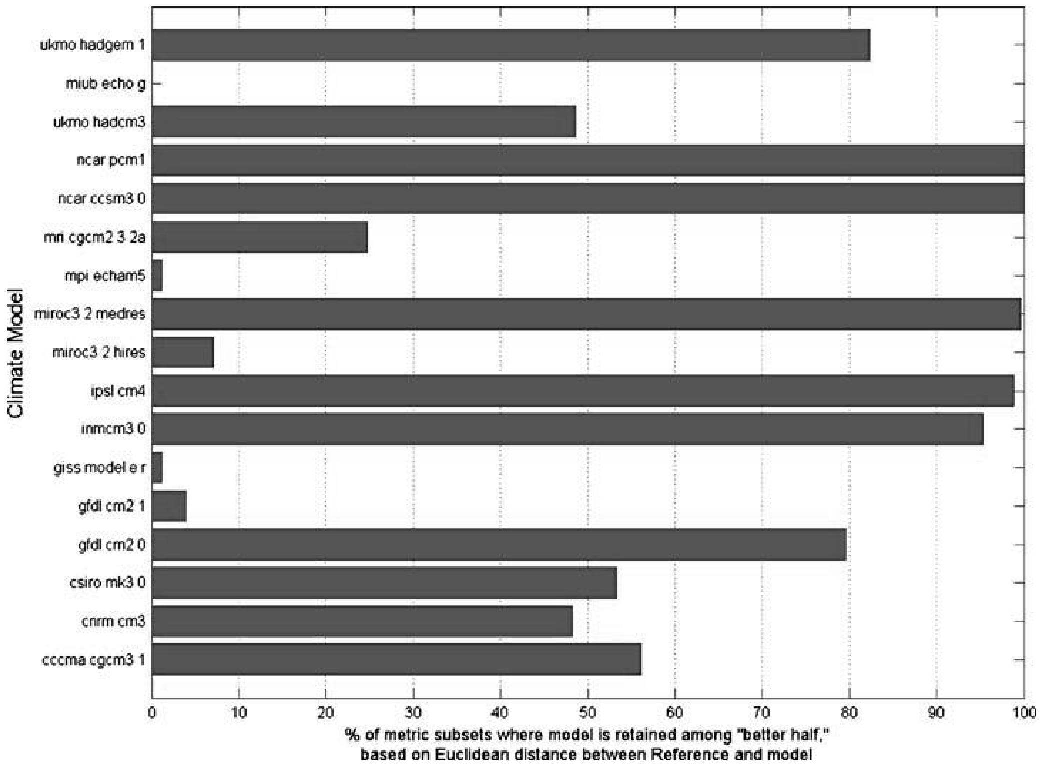


**Fig. 3** Sensitivity of model culling results to choice of NorCalP metrics subset (Table 2). All combinations of one to eight NorCalP metrics are considered. For each metrics set, relative model weights were computed, and a "greater than or equal to median weight" criterion was used to determine model-membership in the projection ensemble. Model-membership frequency was then assessed across metric sets, shown here as a percent-frequency

projections included sufficient scatter and structure so that the spread and central tendency of d ($T$) could be captured with any of a large number of possible subsets and weightings.

For d ($P$), the decision of which models to retain or emphasize was more influential. The central tendency of d ($P$) shifted to a more negative anomaly values compared to the "no change" central value obtained from the full 75-member ensemble. That said, once the less credible models were dropped, the choice on which metric basis to use for culling seemed to be less significant, and the central tendencies and spread of d ($P$) functions were relatively similar.

Comparison of d ($T$,P) based on "No Model Culling" and "Cull Basis: Water Supply" reflects a combination of the impressions drawn from the various d ($T$) and d ($P$) functions. Like d ($T$), the breadth and central tendency of the d ($T$,$P$) relative to the $T$-axis is relative unaffected by decision to cull models. And like d ($P$), the decision to cull models using the Water Supply perspective causes the peak of the density surface to shift toward a more negative anomaly position.

### 3.3 Using climate projection density functions to derive scenario weights

Having fit climate projection density functions, the focus now shifts to the nested set of projection members that might be studied for detailed impacts (i.e. the Impacts Ensemble, described in sections 1 and 2), and their respective plotting positions within each of the density functions. The purpose is to assign relative scenario weights based on scenario

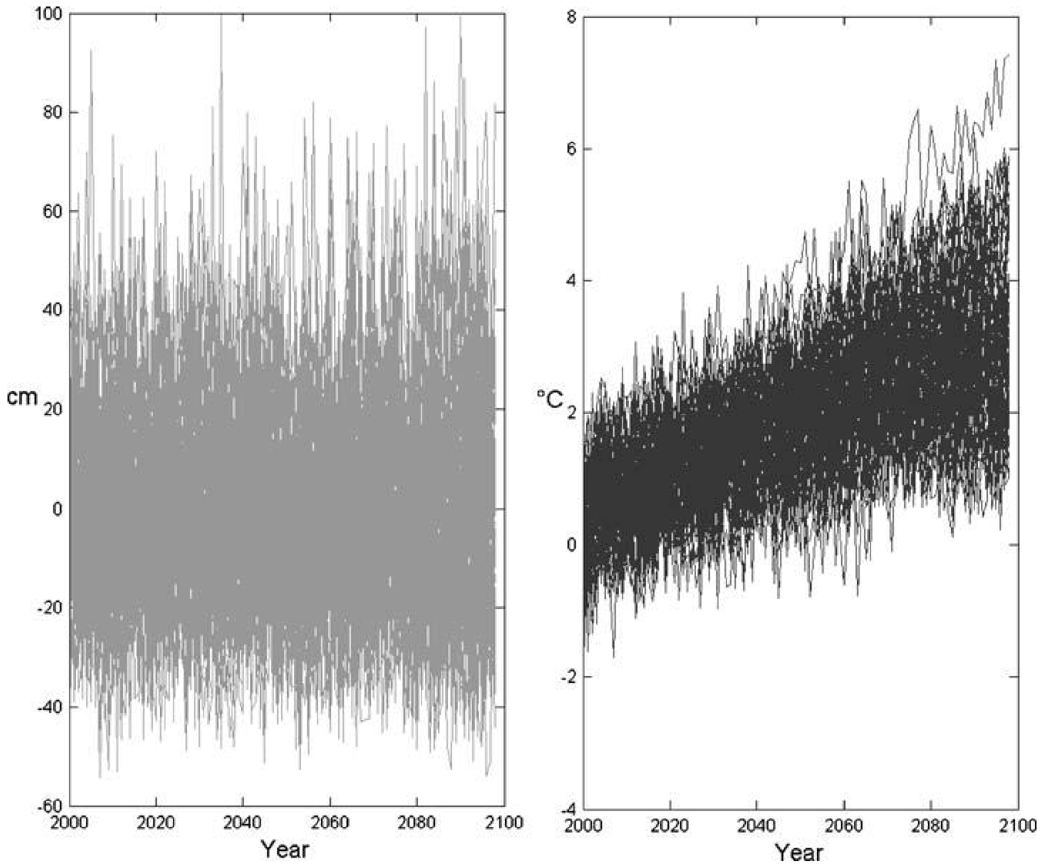


**Fig. 4** Projected annual anomaly time series, computed relative to 1950–1999 NCEP Reanalysis (Kalnay et al. 1996) annual total precipitation (cm) and mean annual surface air temperature (°C) in Northern California near {122W, 40N}. Time series are from the 75 projection ensemble listed in Table 1

densities within either d(*T*), d(*P*), or d(*T*,*P*). As mentioned, the Impacts Ensemble includes 22 of the 75 projection members used to estimate the density functions. The positions of those 22 members are shown on the horizontal axes of Fig. 5a and b, and as circle-cross symbols overlaying the larger "x" symbols on Fig. 6a and b.

Scenario-specific point-densities were identified from six projection distributions: d(*T*) (from Fig. 5a), d(*P*) (from Fig. 5b), or d(*T*,*P*) (Fig. 6a and b), from both the "No Model Culling" and "Cull Basis: Water Supply" functions. These point-densities were then considered in aggregate to imply *relative* scenario likelihoods in the context of a detailed and computationally intensive risk assessment based on these 22 scenarios. Each of the six sets of scenario densities were translated into corresponding sets of scenario weights (Fig. 7) by rescaling each set of 22 densities so that they sum to 22 (i.e. default scenario weight would be one, and a set of 22 density-based weights would have a mean of one).

When focus is placed on a projected quantity or joint-quantities, particular choices of models included in the density estimation process had minimal effect on the relative magnitudes of scenario weights [e.g., compare weights from d(*T*) fit with models from "No Model Culling" versus models from "Cull Basis: Water Supply"]. More significantly, however, the choice of projected quantity was very significant in determining relative scenario weights [e.g., compare weights from d(*T*) relative to weights from d(*P*) or d(*T*,*P*)]. Questions remain as to which projected quantities should steer integration of impacts for the assessment of risk. Addressing this question may be a more important decision for the risk

17-01174_011874;17-01174_011874;17-01174_011875;17-01174_011876;17-01174_011877;17-01174_011878;1...



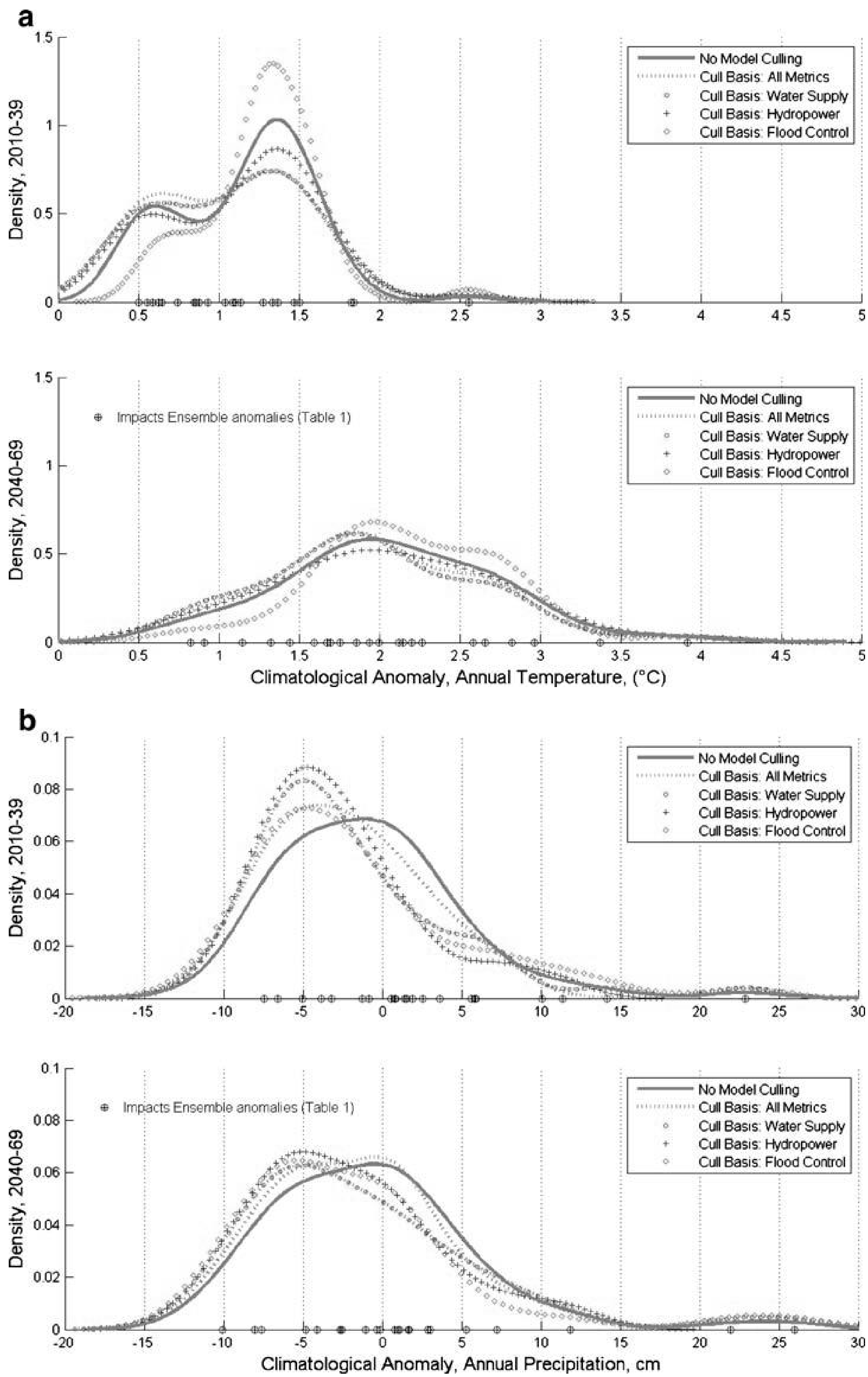

**Fig. 5** **a** Density functions for projected climatological surface air temperature anomaly (i.e. change in projected 30-year mean from 1950 to 1999 mean in Northern California near (122W, 40N)) evaluated for the 2010–2039 and 2040–2069 periods. "No Model Culling" implies density function fit to all 75 projections listed in Table 1. Other legend labels correspond to subsets of these 75 projections, where model-contribution to the subsets is indicated by the credibility-based model subsets listed in Table 3 (columns 2 through 5). *Circle-cross symbols on horizontal axis* show anomaly positions of a 22-member subset (i.e. "Impacts Ensemble") of the 75-member set of fitting projections. **b** Same as **a**, but for projected climatological precipitation anomaly

assessment than the decision on whether to consider model filtering when constructing the climate projection density function. Conceptually, if both projected temperature and precipitation changes are considered in the risk assessment, then perhaps d($T$,$P$) might offer the preferred information. Moreover, if the projected temperature and precipitation trends are correlated, then d($T$,$P$) would also be preferred.

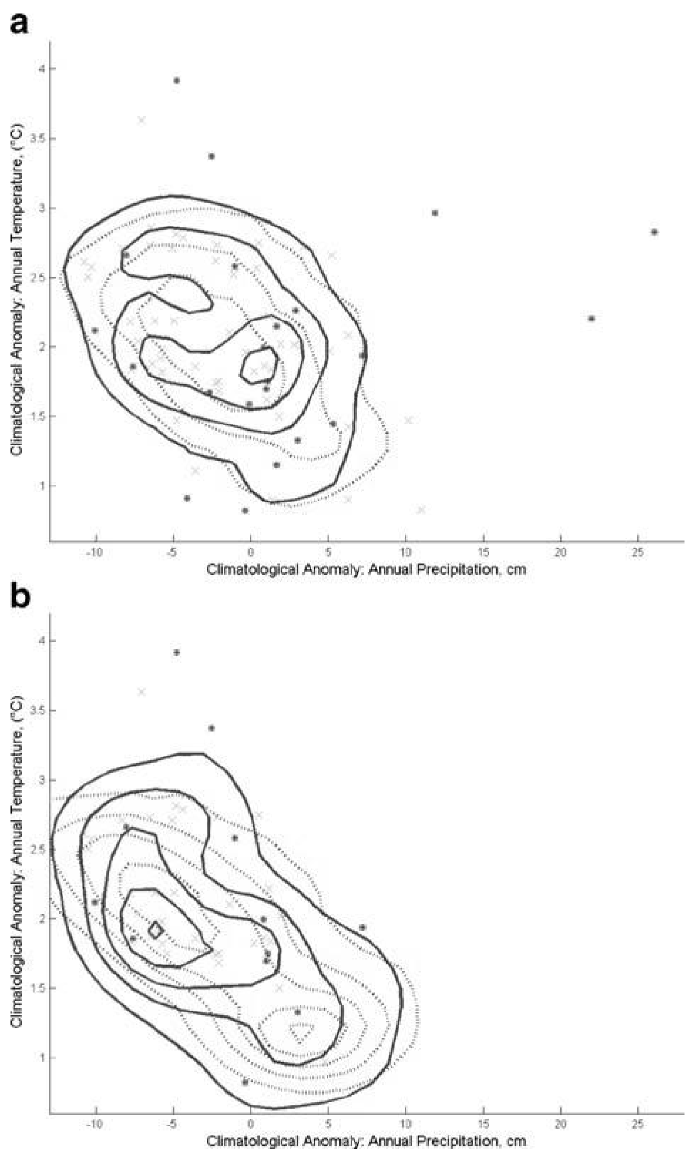


**Fig. 6** **a** Density function for jointly projected climatological surface air temperature and precipitation anomalies (i.e. change in projected 30-year mean from 1950 to 1999 mean in Northern California near (122W, 40N)) evaluated for the 2040–2069 period. *Dashed line* shows 0.05 interval (ascending in value from ~0 at plot perimeter). *Solid contours* show the density surface estimated using the nonparametric technique. *Dashed contours* show the density surface estimated using the second technique (Dettinger 2006). *Light-colored cross symbols* show positions of the joint-anomalies from the 75 fitting projections in Table 1. *Circle-cross symbols on horizontal axis* show anomaly positions of a 22-member subset (i.e. "Impacts Ensemble") of the 75-member set of fitting projections, and overlie the *"x" symbols* marking these same members as they're part of the 75-member fitting ensemble. **b** Same as **a**, but with the density function fit to a retained-model subset of "Uncertainty Ensemble" projections (explaining why there are fewer "x" and circle-cross fitting data relative to **a**). Model culling reflected the Water Supply perspective (Table 2) and associated model membership (Table 3)

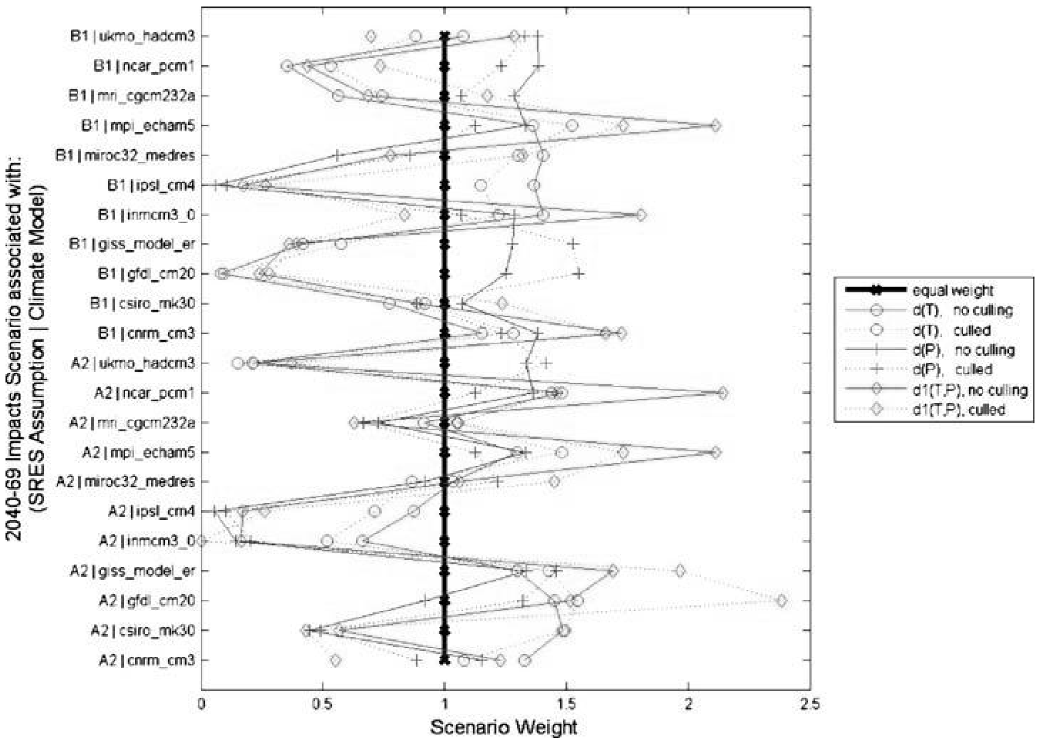


**Fig. 7** Sampled densities from six density functions function coordinates corresponding to projected "Impacts Ensemble" anomalies for the 2040–2069 period. Six functions correspond to three projected conditions, fit to a projection ensemble assembled with or without model filtering. Conditions are projected climatological surface air temperature anomaly (Fig. 5**a**), precipitation anomaly (Fig. 5**b**), and joint anomalies for both (Fig. 6**a**, **b**). Model culling is based on the Water Supply perspective (Table 2) and associated model membership (Table 3)

## 3.4 Discussion

Revisiting the density functions, it is notable that the functions are not smooth and indeed tend to be multi-modal, contrasting from parametric density functions that might have been constructed from the same data. The multi-modal aspects of d($T$), d($P$), and d($T$,$P$) are introduced by the nonparametric density estimation technique used in this case study (which might be more easily interpreted as constructing a smoothed "histogram-like" functions from the fitting data). These effects are somewhat muted when the information from the density functions are presented in terms of cumulative densities, or cumulative distribution functions [e.g., D($T$) and d($P$) derived for the 2040–2069 period from d($T$) and d($P$), respectively, shown on Fig. 8]. For decision-makers, it may be preferable to show scenario possibilities in terms of cumulative distributions or quantiles rather than density functions. For example, decision-makers might hold the risk "value" that planning strategies should accommodate a range of projected climate conditions up to a threshold change exceeded by a minor fraction of projections (e.g., 10%). Applying this hypothetical decision criterion using results from this study, planning would be done to accommodate changes up to [−] deg C or [−] cm of annual precipitation, considering the various D($T$) and d($P$) functions on Fig. 8. If the decision criterion were modified to consider jointly projected occurrence of temperature and precipitation anomalies, then information from D($T$) and d($P$) would have to be replaced by an estimate of D($T$,$P$) using density

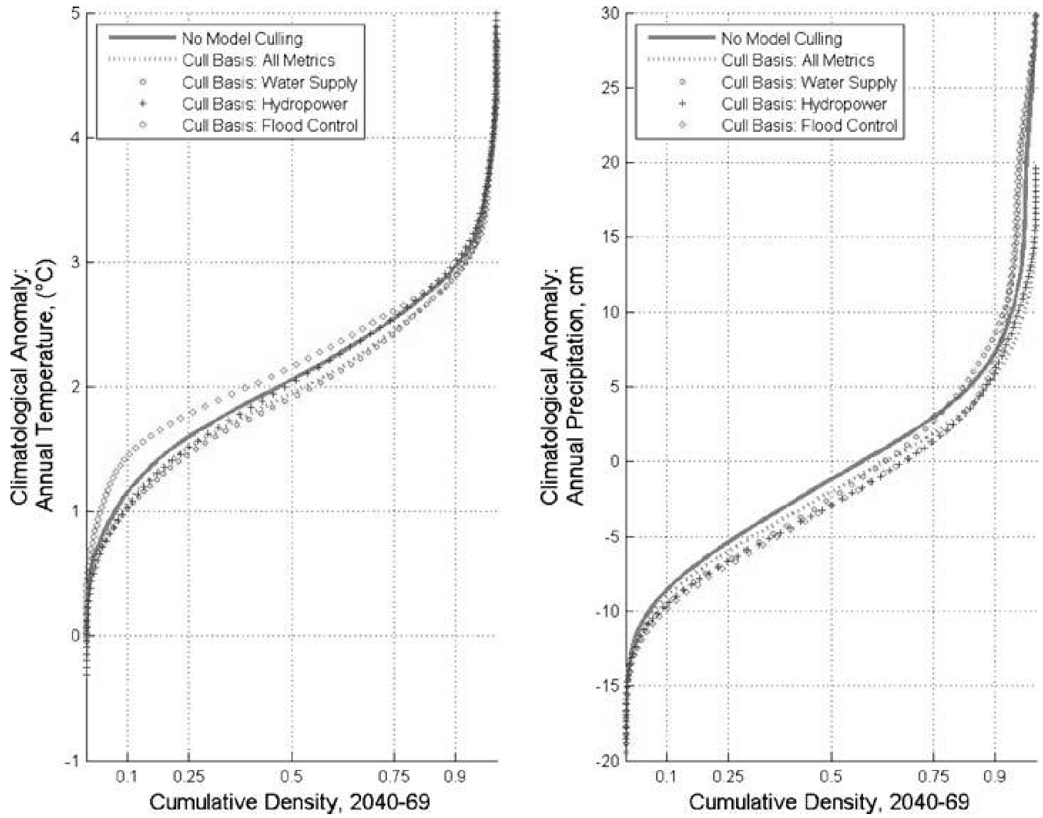


**Fig. 8** Cumulative distribution functions developed from the density functions of projected climatological surface air temperature and precipitation anomalies (Fig. 5**a** and **b**, respectively) evaluated for 2040–2069 period

information in either Fig. 6a or b. However, switching focus back to the task of conducting climate change risk assessment, it is necessary to assign relative scenario likelihoods to individual impacts scenarios. For this objective, density functions, rather than cumulative distributions, are needed given that the former reveal how a specific projection member is positioned within the context of projection consensus and breadth.

Finally, on the matter of how density function form may be sensitive to the fitting technique, the sensitivity of derived scenario weights to fitting technique was explore by reconstruction of d($T$,$P$) for the 2040–2069 period and “No Model Culling” and “Cull Basis: Water Supply,” using the principal component (PC) resampling technique described in Dettinger (2006). Figure 6a and b show density contours from this technique, which can be compared to those developed using the nonparametric technique. As mentioned, comparison of these two surfaces shows that choice of technique had minimal effect on the function’s central tendency and breadth. The distributions obtained from the two methods also share the strong correlation that tends to pair wetter scenarios with (relatively) cooler scenarios and drier scenarios with the warmest scenarios. This correlation, however, was much muted when the resampling approach was adjusted to avoid weighting the more prolific model groups more than those that provided only single realizations of each model/emissions scenario combination (not shown). Further comparisons of the two sets of contours will indicate that only the general features of these distributions can be estimated in a confident, methods-independent way.

## 4 Limitations

The present analysis is subject to several limitations. First, note that these methods provide information on climate projection consensus and not the true probability of climate change. Understanding this limitation will be important in a decision-making context where decision-makers may not anticipate the complex appearance of the density functions, which are as stated are essentially smoothed, multi-modal, "histogram-like" functions. The appearance of these functions is set up by use of nonparametric techniques to fit the functions rather than imposing parametric forms (e.g., Gaussian), and that the function was fit to a limited and not necessarily homogeneous projection sample. Once the decision-makers get used to these odd looking distributions, it will be equally important that they not be over-interpreted; that is, some of the multimodality of these distributions is surely artifact rather than signal.

The correct interpretation of such density functions is that they indicate projection consensus within the ensemble of projections considered. Although there may be an inclination to use the density functions to guide statements on "climate change probability," such application should be avoided. The reason is that key climate change uncertainties are not represented within the spectrum of currently available climate projections. To illustrate, consider that for this case study a 75-member projection ensemble served as the basis for fitting density functions, representing information from a heterogenous mix of 17 coupled ocean–atmosphere climate models under two emissions pathways, reflecting various states of modeling capability and a crude cross section of the uncertainties concerning future emissions. Not represented among these projections are the uncertainties associated with the many factors not included in current climate models or in the pathways considered here (e.g., assumed global technological development, distributed energy-technology portfolios, resultant spatial distribution of GHG sources and sinks through times, and biogeochemical interaction with GHG sources and sinks, and many others). For these reasons, it is important to interpret the "climate projection density" functions featured in this analysis as being a characteristic of the ensemble considered and not the full range of uncertainties. In the end, "climate projection densities" are expected to be distinctly different from climate-change probabilities.

It also bears mentioning that the historical 20c3m climate simulations included in the WCRP CMIP3 archive and used here are not strictly comparable, which introduces uncertainty surrounding credibility analysis results and climate projection initial conditions. Although the 20c3m simulations all shared the same primary anthropogenic GHG forcings, the exact combinations of natural radiative forcings and some secondary anthropogenic influences varied from modeling group to modeling group. This, along with the issue of simulating low-frequency natural climate variations discussed earlier, limits our ability to interpret relative model differences meant to be revealed by the credibility analysis.

Other limitations stem from the absence of basic features that are generally required of statistical frameworks, including: (1) requirement to account for the uncertainties of the Reference climate definitions framing the model credibility analysis, (2) a preference for the credibility analysis to be focused *only* on past simulation of the projected quantity, and (3) requirement to account for the interdependence among credibility analysis variables and metrics (i.e. "dimensions" in the distance-similarity framework). Attribute (1) limits the results produced from the present analysis so that it does not fully represent yet another aspect of the uncertainties associated with the projections, in this case, the uncertainty as to

how well the models really do represent the real-world climate. It will be beneficial if future work can be recast to factor in such uncertainties.

Attribute (2) points to a matter of philosophy in the analytical design herein: whether to frame credibility analysis on a model's ability to recreate only past simulation of projected quantities or a *mix* of regionally relevant local and global climate variables influencing the projected quantities, along with their teleconnections (including the projected quantity). When weighing these options, a real-world limitation emerges in that the projected quantities in question include many historical influences besides the GHG trends that motivate development of GHG-based projections. The complex nature of the climate system is also a factor, as projected quantities depend on the fate and evolution of many other variables within the models. The analytical choice to focus only on past simulation of the projected quantities is reasonable if it can be assumed that credibility in projecting a given quantity is informed *completely* by understanding the model's capability in simulating past values of that quantity. However, in the case of regional climate projection, there is recognition that models can produce "correct answers" for different climate variables and specific regional locations for the "wrong reasons." This fact, although contradictive to the preceding philosophy, promotes consideration for a broader mix of variables and metrics in the credibility analysis, on the idea that ability to recreate a mix of regionally relevant variables and metrics during past simulation should be a good indicator of a models ability to project an embedded quantity (or quantities) within that mix.

Considering the mix of regionally relevant climate variables and metrics used to define model credibility, it is reasonable to assume that inter-variable and inter-metric correlations exist, in defiance of consideration (3), because they are sampled from a common modeled or observed climate system. Nevertheless, such variables and metrics are treated herein as being independent dimensions when computing distance-based model-to-reference similarity. Perhaps future work could focus on modifying the credibility analysis to be framed around a more limited set or transformed set of regionally relevant variables and metrics that are essentially uncorrelated, thereby avoiding the issue of inter-variable and inter-metric correlations affecting interpretation of computed similarity distance.

Finally, focusing on greater numbers of variables and metrics tended to work against the reasonable objective of using credibility analysis to reduce perceived projection uncertainty by focusing on scenarios produced by a set of "best" models. Our results showed that the cumulative differences between models became more muted as more variables and metrics were considered. This particular case study was framed with a goal to identify a "more credible half" of the available models upon which to focus attention (much like the approach used by Milly et al. (2005) and to explore how such model selections affect density function development and density-based scenario weights.

## 5 Summary and conclusions

A methodology has been developed for use in regional assessments, to evaluate the relative credibility of models providing twenty-first century climate projections based on their relative accuracies in simulating past climate conditions. The method rests on the philosophy that the relative credibility of a given model's climate projections among those of other models can be inferred from the model's performance in recreating twentieth century climatology compared to other models. A distance-similarity approach was used to compare among models, where modeled twentieth century climate differences were measured from reference observations of

several regionally relevant climate variables and statistical metrics. Computed distances were then translated into relative model weights, which were then used to select (and possibly weight) among models when estimating climate projection densities.

Case study application of these methods for the Northern California region indicates that:

- Credibility analysis based on multiple climate variables and metrics allows models to be distinguished according to more comprehensive simulation performance. However, use of a greater number of variables and metrics led to less apparent distance-based differences among models.
- Credibility analysis based on a more limited set of variables and metrics led to greater apparent distance-based differences among models. However, the resultant model weights and subsequently use of weights to filter models produced model-culling decisions that depend greatly on the (somewhat arbitrary) choice of metrics.
- Using credibility analysis results to cull models and affect construction of climate projection density functions led to some change in the local aspects of the density functions. For functions describing projected temperature change, results showed that the overall function spread and central tendency tended to be more influenced by how inclusive and extensive the original ensemble was (i.e. Uncertainty Ensemble from Table 1) compared to the influence of deciding whether to filter down to a "better half" of models before fitting the functions. That is, the various culling of the projections used to estimate the distributions did relatively little to change either the central tendencies or ranges of the distributions obtained. For functions describing projected precipitation change, results lead to similar impressions, except that the central tendency of the projected precipitation anomalies' were more sensitive to choice of whether to consider model-culling, but not so much to choice of which cull basis to use among the three "perspectives" considered (Table 3).

Revisiting the motivating question of whether relative scenario weights derived from credibility-based density functions (as framed by these methods) were significantly different than those derived from density functions that do not consider model culling, our results suggest that:

- Accounting for model credibility through model-culling prior to fitting the density function has some influence on the relative scenario weights, which could translate into effects on the subsequent risk assessment.
- Perhaps more significantly, the relative scenario weights are relatively more sensitive to the choice of projected quantity (e.g., d($T$), d($P$), or d($T$,$P$)) than to the chosen cull basis (Table 3) prior to estimating the density function describing that quantity.

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# Bias correction can modify climate model simulated precipitation changes without adverse effect on the ensemble mean

**E. P. Maurer[1] and D. W. Pierce[2]**

[1]Civil Engineering Dept., Santa Clara University, Santa Clara, CA, USA
[2]Division of Climate, Atmospheric Science, and Physical Oceanography, Scripps Institution of Oceanography, La Jolla, CA, USA

*Correspondence to:* E. P. Maurer (emaurer@engr.scu.edu)

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**Abstract.** When applied to remove climate model biases in precipitation, quantile mapping can in some settings modify the simulated difference in mean precipitation between two eras. This has important implications when the precipitation is used to drive an impacts model that is sensitive to changes in precipitation. The tendency of quantile mapping to alter model-predicted changes is demonstrated using synthetic precipitation distributions and elucidated with a simple theoretical analysis, which shows that the alteration of model-predicted changes can be controlled by the ratio of model to observed variance. To further evaluate the effects of quantile mapping in a more realistic setting, we use daily precipitation output from 11 atmospheric general circulation models (AGCMs), forced by observed sea surface temperatures, over the conterminous United States to compare precipitation differences before and after quantile mapping bias correction. The effectiveness of the bias correction is not assessed, only its effect on precipitation differences. The change in seasonal mean (winter, DJF, and summer, JJA) precipitation between two historical periods is compared to examine whether the bias correction tends to amplify or diminish an AGCM's simulated precipitation change. In some cases the trend modification can be as large as the original simulated change, though the areas where this occurs varies among AGCMs so the ensemble median shows smaller trend modification. Results show that quantile mapping improves the correspondence with observed changes in some locations and degrades it in others. While not representative of a future where natural precipitation variability is much smaller than that due to external forcing, these results suggest that at least for the next several decades the influence of quantile mapping on seasonal precipitation trends does not systematically degrade projected differences.

## 1 Introduction

In translating simulated precipitation projections produced by general circulation models (GCMs) for local and regional climate impact studies, a process of downscaling is needed (e.g., Christensen et al., 2007; Fowler et al., 2007; Murphy, 1999). While "perfect-prognosis" downscaling estimates fine-scale projections by assuming the predictors are realistically simulated (Eden et al., 2012), any "model output statistics" (MOS, Glahn and Lowry, 1972) approach by design includes some form of bias correction to remove the time-invariant GCM biases, allowing the signal, or change, simulated by the GCM to be isolated to some degree from the systematic errors. This is critical in applications such as hydrology, where runoff is a nonlinear function of precipitation, and so is highly sensitive to model biases.

A common method for bias correction is quantile mapping (QM), which has been shown to be an effective method for removing some GCM biases at relatively little computational expense (Li et al., 2010; Maraun et al., 2010; Panofsky and Brier, 1968; Piani et al., 2010; Themeßl et al., 2011; Wood et al., 2004). This method has been employed in creating several widely used data sets of downscaled GCM output for the United States and global land areas (Girvetz et al., 2009; Maurer et al., 2014). The use of these data sets in hundreds of

studies, and the extensive application of QM by many others, has led to recent efforts to study some of the assumptions and effects of QM bias correction (Maraun, 2012, 2013; Maurer et al., 2013).

One important effect of QM is that it can change the GCM trend, so that the raw GCM simulated change is modified during the bias correction process, an effect that can be large relative to other sources of uncertainty such as variability among GCMs (Brekke et al., 2013; Hagemann et al., 2011; Maraun, 2013; Pierce et al., 2013; Themeßl et al., 2011). This has raised concerns regarding the effect of modifying the precipitation change simulated by GCMs, especially for water-constrained regions where climate adaptation plans hinge on projected changes in water supply (Barsugli, 2010).

In this paper we examine the effect of QM on simulated precipitation changes between two historic periods, and focus on the question of whether the simulated changes are systematically altered by QM.

While historic GCM simulations include the climatic response to forcings such as changes in atmospheric greenhouse gas concentrations, solar variability, etc., they are unsynchronized with historic natural variability (Eden et al., 2012). This natural, or internal, variability of precipitation can be dominant even at timescales as long as 50 yr (Deser et al., 2012; Maraun et al., 2010), and may play a substantial role in GCM variability in future projections through the mid-21st century (Hawkins and Sutton, 2011). Thus, the differences in a regional precipitation change between two periods in a GCM's historic simulation compared to the observed change result from both GCM biases in sensitivity to external forcing and the fact that natural variability is not synchronized with the observed record. Only the former represents a bias in the GCM. To lessen this effect, this study uses model output contributed as part of the Atmospheric Model Intercomparison Project (AMIP) experiment. In these AMIP model runs the simulated natural variability is more closely tied to observations, since observed sea surface temperatures and sea ice are imposed on the atmospheric model, with the same greenhouse gas concentrations as the historical simulations, with simulations performed by an atmospheric general circulation model (AGCM). This provides a test where the effects of unsynchronized low frequency natural variability between the models are diminished relative to unconstrained historic runs. The improved representation of trends in AMIP simulated precipitation, as compared to unconstrained historical runs, has been demonstrated (Hoerling et al., 2010).

In this study we do not separate the different sources of variability, but apply a QM bias correction as it is typically done, where the QM recognizes the difference between a simulated and observed variable (calling the difference "bias"), but is blind to the source of the difference. As the sources of this aggregate "bias" change in the future, for example, when the precipitation trends forced by increased atmospheric greenhouse gas concentrations dominate regional precipitation variability, it is conceivable that the effect of QM on the simulated trends may change. It is also possible that the relative importance of different mechanisms driving regional precipitation (e.g., large-scale circulation, orographic enhancement, convective storms) will change in the future (Cloke et al., 2013; Maraun et al., 2010), altering the climate model biases and ultimately the effect of QM on trends. Thus, the findings from this experiment should be limited to the historic period and the next few decades, when natural precipitation variability constitutes a similar proportion of the variability as over the three most recent decades.

As noted by Eden et al. (2012), techniques such as QM cannot correct for certain types of biases, such as GCM errors in large-scale circulation producing storm tracks very different from observations. Thus, Eden et al. (2012) suggest that QM only be applied to the portion of the bias due to climate model parameterization or orography; to apply QM to the aggregate bias as done here (and in most applications of QM) can result in less robust bias removal. It should, however, be emphasized that this study does not examine the effectiveness of QM at reducing differences between observed and simulated precipitation, but only its effect on mean precipitation changes over multi-decadal timescales. This experiment examines whether there are coherent modifications induced by QM to the simulated precipitation changes, and if so, whether they might have a tendency to improve or degrade the projected changes.

## 2 Methods and data

As an observational baseline, we used the daily precipitation dataset of Livneh et al. (2013), which has a spatial extent of the conterminous United States, a spatial resolution of 1/16° (approximately 6 km), and includes the period 1915–2011. The period from 1979 (the beginning of the AMIP model output) to 2005 was aggregated to a 1° spatial resolution for this bias correction exercise, which is a typical spatial resolution used when bias correcting GCMs (e.g., Li et al., 2010; Wood et al., 2004). The 1° spatial scale was selected here to correspond to a scale finer than the highest resolution climate model used in this study. We included only those 1° cells where at least 25 % of the area was land area included in the Livneh et al. (2013) data set.

We obtained simulated daily precipitation from the historical AMIP runs for 11 AGCMs, listed in Table A1, from the CMIP5 multimodel ensemble archive (Taylor et al., 2012). For all of the AGCMs we used the run identified as r1i1p1, with the exception of GISS-E2-R for which we used r6i1p1 since that had the available variables and periods for this study. From the CMIP5 AMIP runs we extracted the 1979–2005 period and bilinearly interpolated the data onto the same 1° grid as the observations.

QM is then applied (independently) to each 1° grid cell in the domain. QM is extensively discussed elsewhere (e.g., Gudmundsson et al., 2012; references cited above) and only

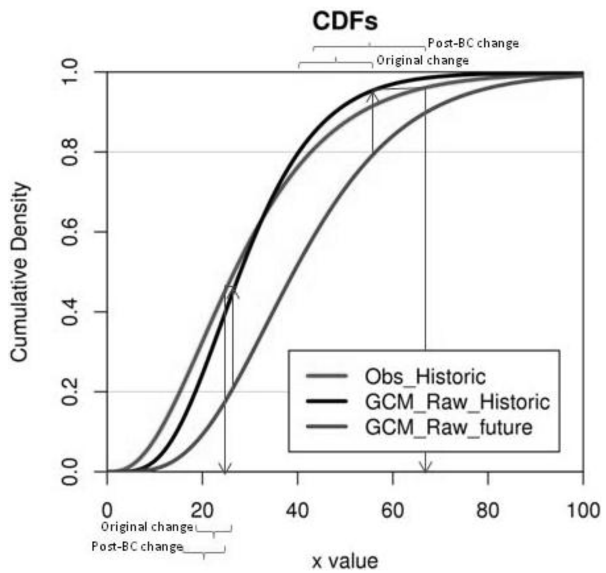


**Fig. 1.** Cumulative distribution functions for a synthetic demonstration set of observed, GCM simulated historic, and GCM projected future precipitation data.

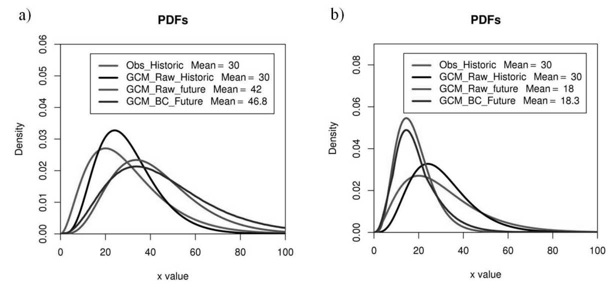


**Fig. 2.** Probability density functions for the same synthetic data in Fig. 1, but including the post-bias correction GCM future projection.

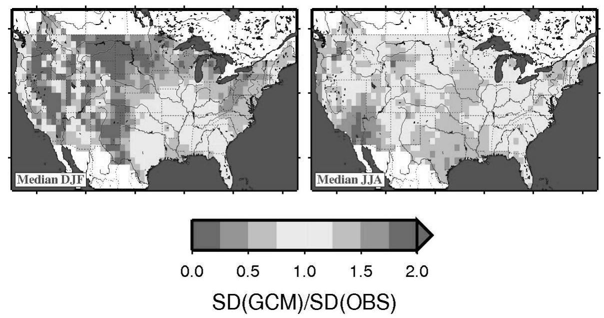


**Fig. 3.** Ensemble median of the ratio of the standard deviation (SD) for the GCMs to the SD of the observations for daily precipitation during DJF and JJA for 1979–1993.

a brief summary is presented here. QM bias correction is an empirical statistical technique that matches the quantile of an AGCM simulated value to the observed value at the same quantile. The quantiles are determined by sorting AGCM output and observations for the same historical base (or calibration) period, and constructing cumulative distribution functions (CDFs) for each. We used a version of QM bias correction essentially following Maurer et al. (2010), with one variation. Maurer et al. considered each month independently, so that for January a 15 yr period would have a CDF defined by 31 days $\times$ 15 yr $=$ 465 points. One modification for this application is that, to avoid abrupt inconsistencies between months, we used a moving 31 day window centered on each day, producing a separate set of CDFs for each day of year (Dobler et al., 2012; Thrasher et al., 2012). This method employs a nonparametric quantile mapping; that is, there is no fitting of a theoretical probability distribution to the data in creating the CDFs. While both parametric and nonparametric approaches are widely used in QM, nonparametric methods have shown higher skill in reducing systematic errors in modeled precipitation (Gudmundsson et al., 2012).

The period 1979–1993 is used to train the QM, which is then applied to 1994–2005. The difference in precipitation between 1994–2005 and 1979–1993 is assessed both before and after bias correction. We compared the raw interpolated AGCM (raw) and the bias corrected (BC) shifts relative to observations (obs) in precipitation between the two periods for winter (DJF) and summer (JJA). We used a difference in daily precipitation, in millimeters, as a metric, for example:

$$\Delta P_x = \overline{P}_{x(1994-2005)} - \overline{P}_{x(1979-1993)}, \mathrm{mm\,d^{-1}}, \quad (1)$$

where the subscript $x$ is either obs, raw or BC for observations, raw AGCM, or bias corrected AGCM precipitation, and the overbar indicates a mean for the period. To quantify the effect of the BC on the precipitation change between the two periods, we used a trend modification index, TM, defined as

$$\mathrm{TM} = |\Delta P_{\mathrm{bc}} - \Delta P_{\mathrm{obs}}| - |\Delta P_{\mathrm{raw}} - \Delta P_{\mathrm{obs}}|, \mathrm{mm\,d^{-1}}, \quad (2)$$

where vertical bars are the absolute value. This index has the property of having values greater than 0 where the bias correction degrades the correspondence between the climate model and observed precipitation changes. Equation (2) emphasizes that we examine changes in terms of differences rather than ratios (or fractions).

## 3 Results and discussion

Figure 1 presents an illustration of one way in which quantile mapping can change the trend or shift simulated by a GCM. The plot uses a synthetic data set of daily precipitation generated using a gamma distribution, similar to Piani et al. (2010). The data for synthetic observations have a mean of 30, as do the data for synthetic GCM for the overlapping historic period, so the GCM shows no bias in mean daily precipitation for the overlapping historic period, but is given a −30 %

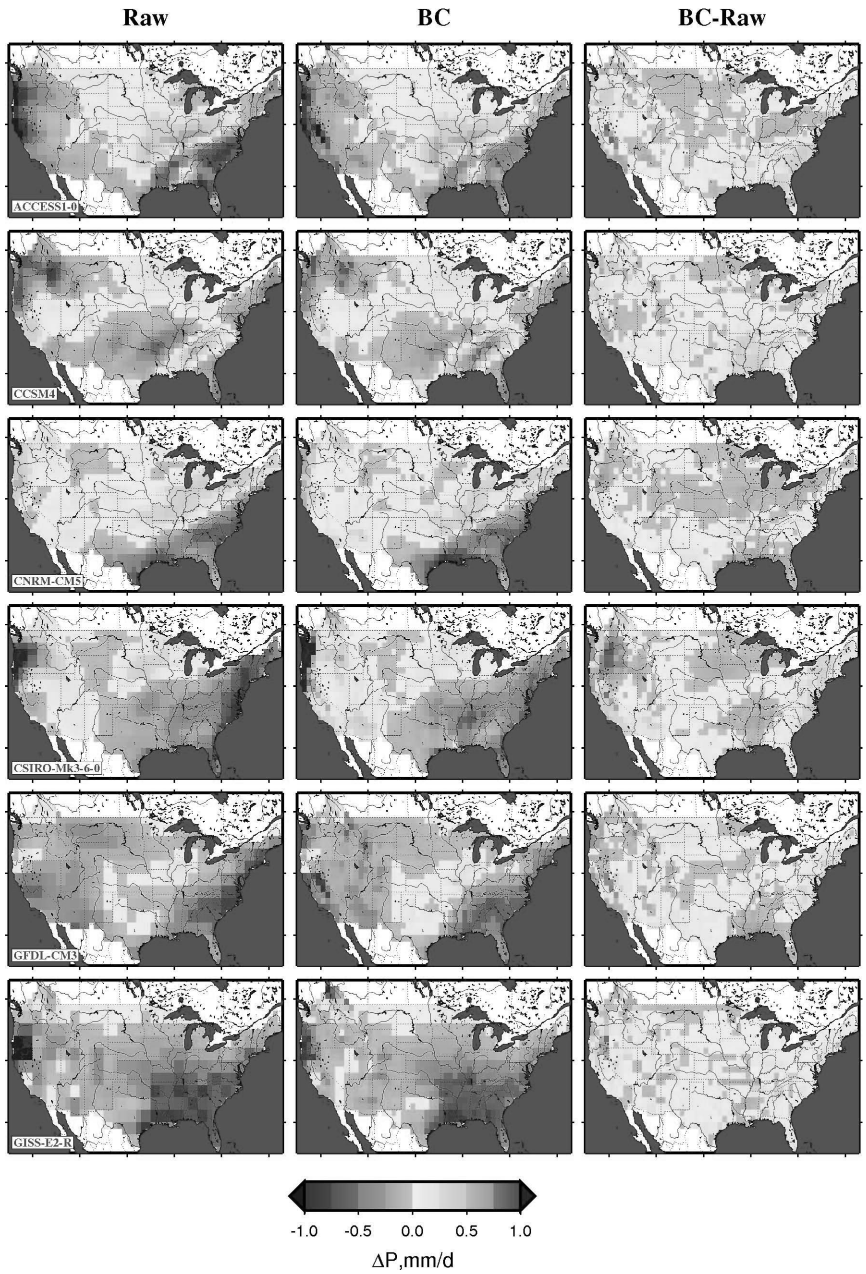


**Fig. 4.** For GCMs 1–6, the change in mean DJF precipitation between 1979–1993 and 1994–2005 for the raw GCM output (left column) and bias corrected GCM output (center); the difference between the two is in the right column.

bias (underestimate) in standard deviation. The future GCM projection assumes a 40 % increase in mean relative to the historic GCM. The arrows indicate what would happen during quantile mapping of the GCM's raw future projection for two values corresponding to a low (20th percentile) and high (80th percentile) value. For the 80th percentile value, the future GCM value of 55.7 corresponds to a 95th percentile for the raw historic GCM data. The 95th percentile of the observations is 63.7, which becomes the new bias-corrected future GCM value. Similarly, the 20th percentile raw future GCM value of 25.9 is mapped to a bias corrected value of 23.8. The brackets above and below the plot show that the quantile mapping increases the simulated change at both values, with the original changes being the difference between the raw future and historic GCM, and the post-BC change being the difference between the bias corrected values and the

17-01174_011903;17-01174_011903;17-01174_011904;17-01174_011905;17-01174_011906;17-01174_011907;1...



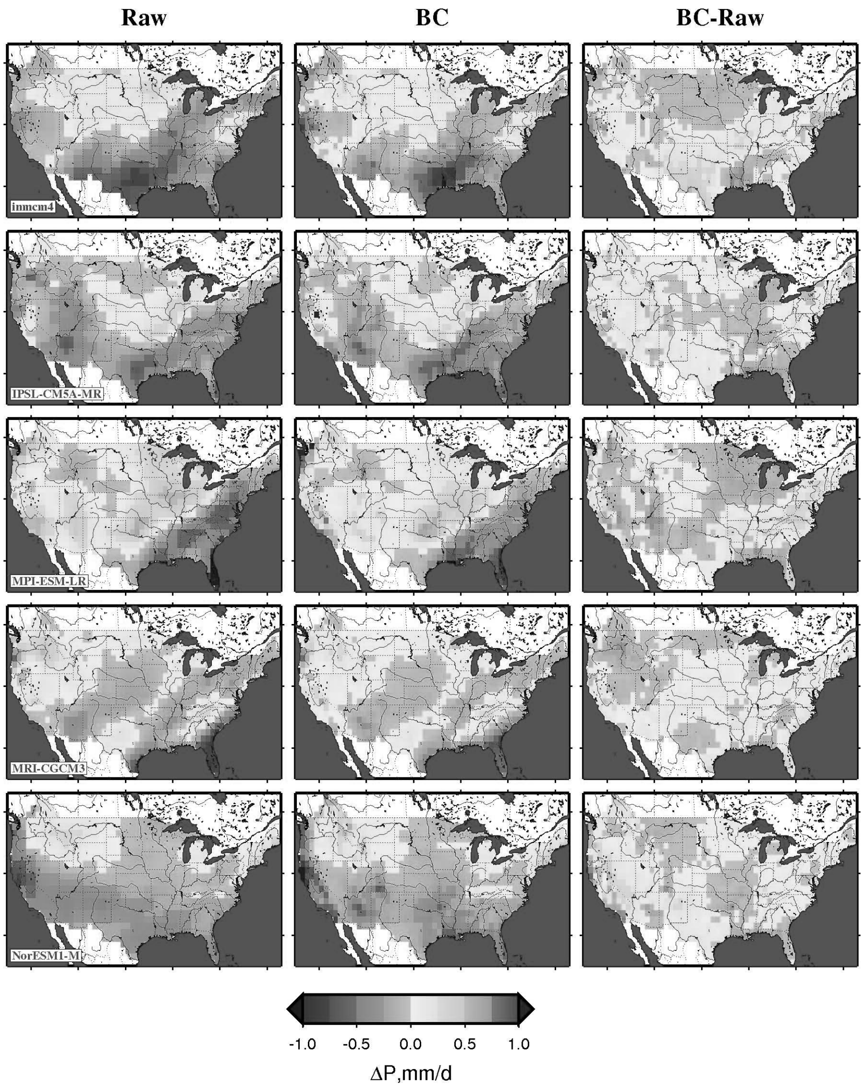


**Fig. 5.** Same as Fig. 4 but for GCMs 7-11.

observations. The original change at the 80th percentile is 15.6, and the post-BC change is 21.2; at the 20th percentile the original change is 7.4 and the post-BC change is 8.6.

Figure 2 continues with the synthetic data from Fig. 1, but presents probability distribution functions to illustrate more clearly the effect of the imposed bias in variance on the projected change through the bias correction process. Figure 2a shows that the 40 % increase in the raw GCM data is amplified to a 56 % increase by the QM process. If the synthetic distribution were symmetrical, a comparable decrease in GCM simulated mean would be amplified in the opposite direction, and if projected changes were negative as often as positive, then this amplifying effect would be offset and the quantile mapping would have little net effect on trends or shifts. However, because the distributions in Fig. 2a are bounded and positively skewed, even when equivalent increases and decreases are projected, the net effect of an underestimated variance is for quantile mapping to amplify the trend. This is illustrated in Fig. 2b, where the same observed and raw GCM historic distributions are used, but a 40 % decrease in mean value is imposed on the raw future GCM projection. In this case, the shift is only slightly affected by quantile mapping, changing from a 40 % decrease to a 39 % decrease. Thus, an underestimate of variance for a bounded, positively skewed distribution, common for daily precipitation (Wilks, 1989), will have a tendency during quantile mapping bias correction to amplify projected trends or shifts (Maraun, 2013). Conversely, overestimation of variance will tend to dampen projected trends.

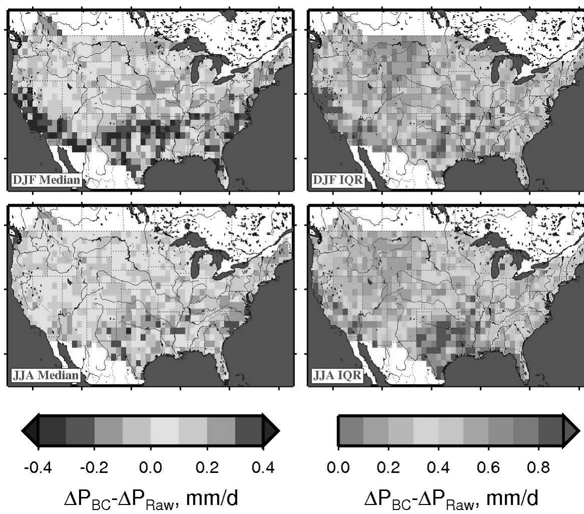


**Fig. 6.** Ensemble median difference between the BC and raw differences in precipitation between 1994–2005 and 1979–1993 for DJF (top row) and JJA (bottom row). Right column is the interquartile range (IQR), defined as the 75th percentile minus the 25th percentile.

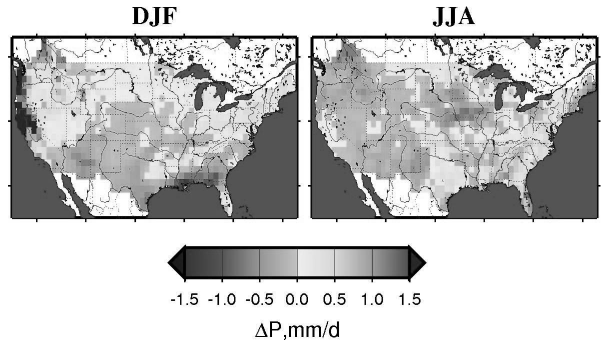


**Fig. 7.** Difference between observed seasonal mean precipitation of 1994–2005 and 1979–1993.

The connection between bias correction, the variance, and the trend can be understood more clearly by analyzing a simple change in the median. Let $M_{0.5}^{\mathrm{E}}$ be the model median in the early period, with the subscript 0.5 indicating the quantile (50th percentile or median) and the superscript E for the early period. The model median in the late period is then $M_{0.5}^{\mathrm{L}}$, and we are interested in the effect of bias correction on the model-predicted change in median, $M_{0.5}^{\mathrm{L}} - M_{0.5}^{\mathrm{E}}$. Will bias correction amplify or reduce this change? Assuming the change is nonzero, we can write $M_{0.5}^{\mathrm{L}} = M_{p}^{\mathrm{E}}$, where $p \neq 0.5$ is the percentile value of the new model median in the old model distribution. The raw model-projected change in median is then simply $M_{p}^{\mathrm{E}} - M_{0.5}^{\mathrm{E}}$. QM will map a model value with percentile $p$ in the early period to the observed value at the same percentile: $\mathrm{QM}(M_{p}^{\mathrm{E}}) = O_{p}^{\mathrm{E}}$, where $O$ indicates an observed value. The bias corrected change in median is therefore $\mathrm{QM}(M_{p}^{\mathrm{E}}) - \mathrm{QM}(M_{0.5}^{\mathrm{E}}) = O_{p}^{\mathrm{E}} - O_{0.5}^{\mathrm{E}}$. Since we have already stipulated $p \neq 0.5$, we can compare the magnitude of the bias corrected to original change in median using a bias-correction ratio (BCR):

$$\mathrm{BCR} = \frac{O_{p}^{\mathrm{E}} - O_{0.5}^{\mathrm{E}}}{M_{p}^{\mathrm{E}} - M_{0.5}^{\mathrm{E}}}. \tag{3}$$

$\mathrm{BCR} < 1$ (bias correction reduces the model change) when the model difference between the $p$th percentile and median value is larger than the observed difference between the $p$th percentile and the median value – i.e., when the model has too much variance. Similarly, where $\mathrm{BCR} > 1$, bias correction will increase the model change (when the model has less variance than observed). Furthermore, Eq. (3) indicates that QM does not alter the sign of the model-predicted change (at least in this simple case) and that the alteration of the change is insensitive to any positive or negative bias between the model and observations, being affected only by the relative variance of the two. From this simple synthetic demonstration it can be inferred that, if there were a preponderance of GCMs with biases in variance in the same direction, the net effect of QM on the simulated difference between eras could be systematically in one direction, even with random biases in the mean.

In reality trends in non-normally distributed variables cannot be represented just by changes in the median, and GCMs exhibit much more complex biases than simply an overestimate or underestimate of variance, with differing biases at different times, in different seasons, and at different quantiles, for example (Boberg and Christensen, 2012; Maurer et al., 2013; Themeßl et al., 2011), all of which can affect the modification of GCM simulated changes by QM. Thus, simply characterizing a GCM as exhibiting a certain bias in standard deviation will not exactly predict the effect of bias correction on trends. In any case, for illustration, Fig. 3 shows the ensemble median of biases in standard deviation, expressed as a ratio of simulated to observed standard deviation, for the 11 AGCMs included in this study for two seasons: DJF and JJA. This shows areas where there appears to be consistent underprediction of standard deviation by a majority of AGCMs, such as in the southeastern portion of the domain. This means there may be a potential for the trends in the raw output from many of the AGCMs to be modified by the bias correction process.

Analyzing actual precipitation simulations, Figs. 4 and 5 show that bias correction does not generally change the pattern of regions that are simulated as becoming wetter or drier, as suggested by Eq. (3), since the left and center columns are broadly similar. However, the difference between the bias corrected and raw AGCM precipitation changes for some regions is of a magnitude that is comparable to the projected change itself. While the differences (right columns in Figs. 4 and 5) show that there are large areas where the BC process

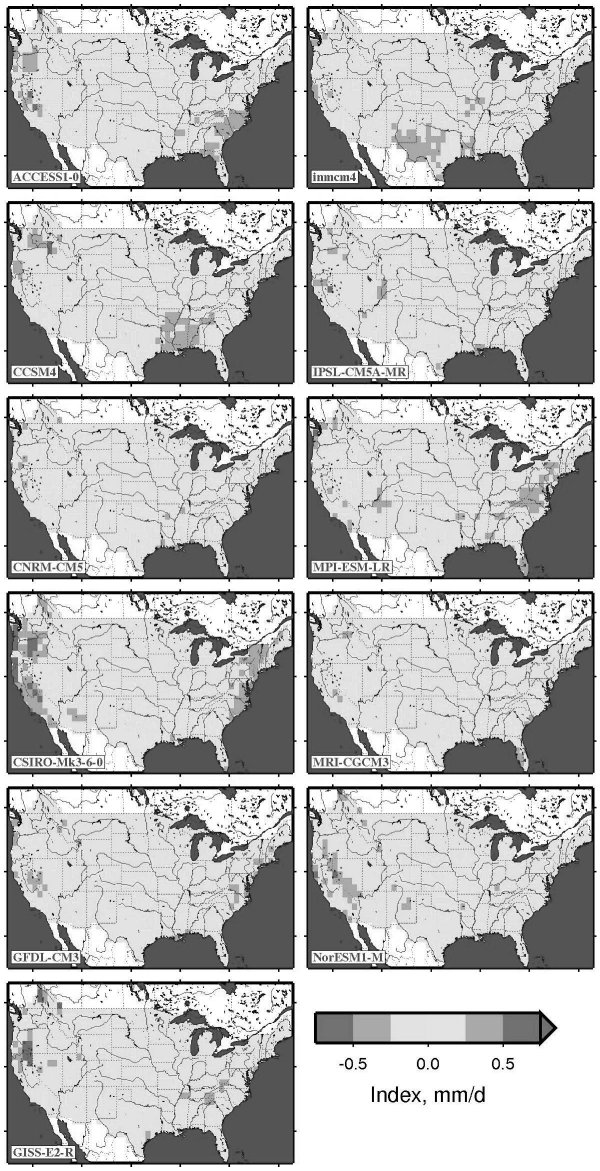


**Fig. 8.** For DJF, the TM index (described in the text) values for each GCM.

produces a wettening or drying effect for each AGCM, there is considerable variation among the AGCMs.

While not shown here, for JJA precipitation the changes due to the BC process for each AGCM appear slightly less prominent than for DJF relative to the raw AGCM precipitation changes between the two periods. Figure 6 shows the ensemble median change and the interquartile range (IQR) between the BC and raw precipitation differences for the two periods for both DJF and JJA. The left column represents the ensemble median effect of BC on the seasonal mean precipitation difference between 1994–2005 and 1979–1993. The IQR in Fig. 6 is analogous to the standard deviation, representing the spread of the AGCMs about the median. In general, where the ensemble median has the greatest magnitude, the IQR is also large, indicating high variability among the models in the effect of BC on the precipitation change. The changes in precipitation differences induced by the BC process in Fig. 6 can be a cause for concern. While in large portions of the domain they are small in comparison to the observed difference in mean precipitation between the two periods (Fig. 7), at many individual points the effect can be substantial. For example, for the DJF median panel in Fig. 6, there is a swath of dark blue grid cells along the southern west coast, with a median effect of the BC on the precipitation trend of $0.4\,\mathrm{mm\,d^{-1}}$ or higher. This would be an important modification based on the observed differences in Fig. 7, with a median change between the periods of 0.5–$1.0\,\mathrm{mm\,d^{-1}}$. Second, the DJF IQR for these cells is greater than $0.5\,\mathrm{mm\,d^{-1}}$, indicating that 25 % of the AGCMs would show trend modifications by BC in excess of approximately $0.65\,\mathrm{mm\,d^{-1}}$ (the median plus half of the IQR), which is on the order of the observed trend in Fig. 7. This latter point makes clear the importance in using an ensemble of climate models rather than one or a few, since the regions of enhancement/reduction of trends are not coherent across different models and the effect diminishes when combined into an ensemble.

Perhaps more importantly, in Fig. 6, some areas where the BC process appears (in the median) to produce much wetter conditions than the raw AGCM are also areas where the observed difference between the 1994–2005 and 1979–1993 periods is considerably higher than the AGCMs simulate. One example is the Pacific northwest, where Figs. 4 and 5 show more than half the models simulating drying DJF conditions between 1994–2005 and 1979–1993, in distinct contrast to the wettening trend in the observations (Fig. 7). It should be emphasized that the BC only adjusts the quantiles of the AGCM to match those of observations within a 15 yr training period – there is no attempt to match trends, either within the 15 yr training period or over longer periods. Thus, any trends are inherited directly from the AGCM, though the QM can, as discussed above, modify these.

This raises the question of whether the change induced by BC in the precipitation change (or trend) between the two periods degrades or improves the correspondence between simulated and observed trends in any systematic way. In terms of the link between the trend modification and variance, this is equivalent to asking if models with variances that are too large tend to have trends that are too large, and vice versa. The TM index described above is used to illustrate this for each AGCM for DJF in Fig. 8. Values in blue (negative values) show where the effect of the BC results in an improved representation of the observed difference in precipitation between the two periods, and red (positive values) indicate a degraded precipitation trend due to BC. It is evident that over the entire domain, for each AGCM there are

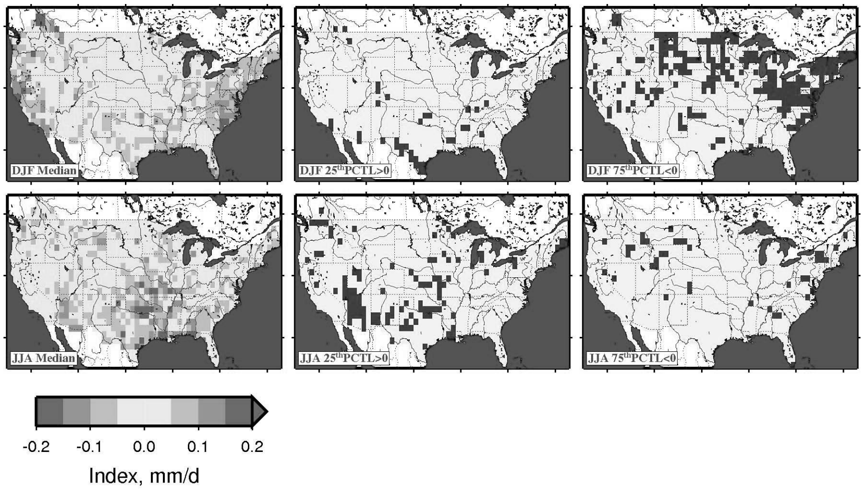


**Fig. 9.** For DJF and JJA, the ensemble median TM index value (left panels), the locations of grid cells (dark rectangles) where the 25th percentile TM index value exceeds 0 (center panels), and the grid cells where the 75th percentile value is less than 0.

areas of improved and degraded precipitation trend representation due to BC. Regions with improved or degraded skill vary from model to model, with no apparent geographical consistency. In sum, the errors in an individual model's variance appear unrelated to the errors in the model's trend.

Figure 9 summarizes the results for the ensemble in Fig. 8 and the similar ensemble for JJA. The median TM values (left panels) tend to lie close to zero, and neither degraded (TM $> 0$) nor improved (TM $< 0$) values dominate the picture for either DJF or JJA. The center panels highlight regions where 75 % of the AGCMs show a degraded change in precipitation (relative to the observed change) due to the BC process. These cases constitute 4.3 % of the grid cells for DJF and 13.0 % of the grid cells for JJA. The right panels show the grid cells where 75 % of the AGCMs show improved correspondence with the observed change after BC. These cover 26.2 and 4.5 % of the domain for DJF and JJA, respectively.

This suggests that with an ensemble of 11 AGCMs as used in this effort the BC produces no consistent improvement or degradation in the simulated AGCM precipitation change. While the effect of BC on the trend can be significant, it tends as often as not to bring AGCM simulated trends closer to observed trends for the periods used in this study. However, there are isolated locations where the trend appears to be degraded for most model simulations, which could be of particular interest for impacts studies. One such case is the southwestern portion of the domain, where Fig. 9 (center panels) shows the grid cells for which JJA precipitation trends are degraded for 75 % of the AGCM simulations by the BC process. For these locations, it may be beneficial to retain the raw GCM simulated trend during impacts analysis studies. Conversely, in Fig. 9 (right panels) there are many grid cells in the northeast where DJF precipitation trends are improved by BC for most of the AGCM simulations.

One of the driving motivations for much downscaling is the investigation of regional and local hydrological impacts of climate change (Fowler et al., 2007). Since the runoff response to changing precipitation is highly nonlinear (Wigley and Jones, 1985), changes in precipitation are amplified in their convolution to runoff changes. This emphasizes the importance in ensuring that the projected precipitation trends not be degraded during the BC process, since the implications would be for even greater biases in projected runoff changes.

## 4 Summary and conclusions

Quantile mapping bias correction has been shown to modify the projected changes, or trends, produced by climate models. This is of critical concern regarding precipitation projections, where changes to the raw climate model output can have significant impacts on the implications for water supply and management in the face of climate change. The resulting discrepancy between the raw climate model output and bias corrected output leaves some ambiguity as to whether the bias correction should be modified to preserve the original climate model simulated changes. It is emphasized that this study is only concerned with the effect of quantile mapping on precipitation trends. It includes no assessment of the effectiveness of quantile mapping at reducing biases, which would be enhanced by considering the different sources of bias.

The historical changes in daily mean precipitation simulated by 11 atmospheric general circulation models, driven by observed sea surface temperatures and sea ice to preserve observed variability in boundary conditions, were examined across the conterminous United States. The differences

were compared between precipitation for two periods, 1979–1993 and 1994–2005 for all AGCMs, both before and after a quantile mapping bias correction, and gridded observed precipitation. We consider winter and summer precipitation separately.

We found that the bias correction did produce different precipitation changes from the raw AGCM output, with a wettening effect in some locations and a drying effect in others. While there was some spatial consistency in regions showing a tendency for bias correction to make the projections wetter or drier, the skill, measured as a correspondence to observed changes, was more variable, with different AGCMs responding to bias correction differently. Taken as an ensemble, the bias correction had no coherent, overwhelming negative or positive effect on the correspondence of the simulated to observed precipitation changes between periods. Reliance on a single AGCM or a small sample of AGCMs however could, for some regions, result in a degraded simulated trend in precipitation due to bias correction.

Based on these results, it does not appear that there is a clear advantage to either preserving the raw AGCM simulated trend in precipitation during bias correction or allowing the trend to be modified by the process. In most locations, as long as a reasonable ensemble size is used, even though the trend in seasonal precipitation may be modified in the process, it may be as likely as not to be beneficial to do so. Similar to the suggestions by others (Cloke et al., 2013), it may be prudent for practitioners to examine the projected trends in raw AGCM output as well as in bias corrected output, to be completely transparent as to the effects of bias correction on trends.

These findings are limited to the extent of this study, namely seasonal mean precipitation for the observed periods used here. This focus was motivated by the observation of changes in trends in mean precipitation produced by quantile mapping. Since changes in the magnitude of extreme precipitation events are important for assessing many impacts to society, future efforts will examine the effect of quantile mapping bias correction on trends in extreme events. Quantile mapping can have different effects at the tails of distributions (Li et al., 2010), and changes in the projected trends in extreme events due to quantile mapping have not been explored. Furthermore, the bias correction was performed at a 1° spatial scale, so that the observations are comparable to the scale of the climate models. At finer scales, the biases between interpolated AGCM output and observations would be expected to be much more heterogeneous, and the impact of quantile mapping bias correction at finer scales could be quite different from that found here, though employing quantile mapping to downscale to fine scales has been found to be problematic (Maraun, 2013).

**Table A1.** Climate models used in this study.

| | Modeling center | Model name |
|---|---|---|
| 1 | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia | ACCESS1.0 |
| 2 | National Center for Atmospheric Research | CCSM4 |
| 3 | Centre National de Recherches Météorologiques/Centre Européen de Recherche et Formation Avancée en Calcul Scientifique | CNRM-CM5 |
| 4 | Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence | CSIRO-Mk3.6.0 |
| 5 | NOAA Geophysical Fluid Dynamics Laboratory | GFDL-CM3 |
| 6 | NASA Goddard Institute for Space Studies | GISS-E2-R |
| 7 | Institute for Numerical Mathematics | INM-CM4 |
| 8 | Institut Pierre-Simon Laplace | IPSL-CM5A-MR |
| 9 | Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology) | MPI-ESM-LR |
| 10 | Meteorological Research Institute | MRI-CGCM3 |
| 11 | Norwegian Climate Centre | NorESM1-M |

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Water Resources Research

RESEARCH ARTICLE
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**Key Points:**
- The fidelity of four common downscaling methods is assessed in current climate
- Some methods have problems with wet days, wet/dry spells, and extreme events
- Most methods have problems with spatial scaling and interannual variability

**Supporting Information:**
- Readme
- Supplemental figures

**Correspondence to:**
E. Gutmann,
gutmann@ucar.edu

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# An intercomparison of statistical downscaling methods used for water resource assessments in the United States

**Ethan Gutmann[1], Tom Pruitt[2], Martyn P. Clark[1], Levi Brekke[2], Jeffrey R. Arnold[3], David A. Raff[4], and Roy M. Rasmussen[1]**

[1]National Center for Atmospheric Research, Boulder, Colorado, USA, [2]United States Bureau of Reclamation, Denver, Colorado, USA, [3]United States Army Corps of Engineers, Seattle, Washington, USA, [4]United States Army Corps of Engineers, Alexandria, Virginia, USA

**Abstract** Information relevant for most hydrologic applications cannot be obtained directly from the native-scale outputs of climate models. As a result the climate model output must be downscaled, often using statistical methods. The plethora of statistical downscaling methods requires end-users to make a selection. This work is intended to provide end-users with aid in making an informed selection. We assess four commonly used statistical downscaling methods: daily and monthly disaggregated-to-daily Bias Corrected Spatial Disaggregation (BCSDd, BCSDm), Asynchronous Regression (AR), and Bias Corrected Constructed Analog (BCCA) as applied to a continental-scale domain and a regional domain (BCCAr). These methods are applied to the NCEP/NCAR Reanalysis, as a surrogate for a climate model, to downscale precipitation to a 12 km gridded observation data set. Skill is evaluated by comparing precipitation at daily, monthly, and annual temporal resolutions at individual grid cells and at aggregated scales. BCSDd and the BCCA methods overestimate wet day fraction, and underestimate extreme events. The AR method reproduces extreme events and wet day fraction well at the grid-cell scale, but over (under) estimates extreme events (wet day fraction) at aggregated scales. BCSDm reproduces extreme events and wet day fractions well at all space and time scales, but is limited to rescaling current weather patterns. In addition, we analyze the choice of calibration data set by looking at both a 12 km and a 6 km observational data set; the 6 km observed data set has more wet days and smaller extreme events than the 12 km product, the opposite of expected scaling.

## 1. Introduction

Many of the impacts of climate change on society are going to be felt at the local level, and even regional-scale problems, such as water resource planning, require detailed spatial information for hydrologic model input. However, currently available climate models (i.e., coupled models of the climate system, including land, atmosphere, ocean, and sea ice) are not able to perform long-term simulations with outputs at spatial resolutions sufficient for use in many impact assessments. As a result, many methods, including statistical and dynamical models, have been proposed to downscale coarse-resolution climate model results to locally relevant information.

There is a large range of statistical downscaling methods available [see *Fowler et al.*, 2007; *Maraun et al.*, 2010; *Schoof*, 2013], but many recent studies of the impacts of climate change in the water sector use rather basic statistical downscaling methods, some of which are primarily bias correction methods. In particular, many impact assessments are based on statistical downscaling methods that simply rescale the coarse-scale precipitation output from climate models to the finer spatial scales necessary for hydrologic modeling [e.g., see *Brekke et al.*, 2009; *Bureau of Reclamation*, 2012; *Brown et al.*, 2012; *Hanson et al.*, 2012; *Miller et al.*, 2013; *Hay et al.*, 2014]. It is important to carefully evaluate the suitability of these downscaling methods for water resource and other applications [*Barsugli et al.*, 2013].

Here we present an analysis of four statistical downscaling methods and assess their fidelity in reproducing precipitation in current climate using an array of metrics. We focus specifically on methods that are used to rescale precipitation from climate models. However, in this work we analyze these statistical methods as applied to a coarse-resolution reanalysis (NCEP/NCAR Reanalysis [*Kalnay et al.*, 1996]) as a surrogate for a

**Table 1.** Sampling of the Availability of Data Sets Developed With the Methods Examined in the Current Study

| Method | Online Availability |
|---|---|
| BCSD, BCCA | http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html |
| BCSD, AR | http://cida.usgs.gov/climate/gdp/ |
| BCSD | http://www.engr.scu.edu/~emaurer/global_data/ |
| BCSD, BCCA, AR | http://earthsystemcog.org/projects/ncpp/downscportals |
| BCSD | https://portal.nccs.nasa.gov/portal_home/published/NEX.html |

climate model, as is commonly done in the statistical downscaling literature [e.g., *Wilby et al*., 2000; *Schmidli et al*., 2006; *Benestad et al*., 2007; *Wetterhall et al*., 2007; *Huth et al*., 2008; *Maurer and Hidalgo*, 2008; *Fasbender and Ouarda*, 2010; *Abatzoglou and Brown*, 2011; *Nicholas and Battisti*, 2012]. Because reanalyses are essentially a series of short-term weather forecasts [*Zhang et al*., 2011], this approach does not consider problems with climate model simulations of regional-scale precipitation, and instead focuses directly on differences in statistical downscaling methods. Additional errors associated with problems in simulating regional-scale precipitation may be present when these methods are applied to climate models, and future work will look at that application. Our approach also does not address the effect these methods have on the climate change signal of a climate model, this too will be addressed in future work. In addition, fidelity in simulating current climate is a necessary, but not sufficient condition to ensure skill in simulating future climate.

The four statistical methods are (1) the Bias Corrected Spatial Disaggregation approach (BCSD) [*Wood et al*., 2004], (2) BCSD applied directly at a daily time step (BCSDd) [*Thrasher et al*., 2012], (3) the Constructed Analog (CA) [*Hidalgo et al*., 2008] approach modified with a bias correction (BCCA) [*Maurer et al*., 2010] as well as a regional application of BCCA (BCCAr), and (4) the Asynchronous Regression approach (AR) [*Dettinger et al*., 2004; *Stoner et al*., 2012]. To distinguish the more typical BCSD approach, which is applied at a monthly time step and disaggregated-to-daily values, from the direct daily approach, we will refer to the typical BCSD as BCSDm. Each method is used to compute daily and 12 km fields of precipitation from the 1.9° reanalysis precipitation data in the NCEP/NCAR Reanalysis. It should be noted that these methods may be referred to as bias correction methods, with statistical downscaling being reserved for methods that relate other climate model fields, e.g., wind speed, humidity, and pressure, to precipitation. However, within the communities that develop and use these methods, they are referred to statistical downscaling methods [e.g., *Wood et al*., 2004; *Maurer et al*., 2010; *Stoner et al*., 2012; *Bureau of Reclamation*, 2012; *Yoon et al*., 2012; *Hwang and Graham*, 2013], as such, we retain that nomenclature here. Within the classification scheme of *Wilby et al*. [2004], BCSDd and AR could be considered transfer functions; BCSDm is a combination of a transfer function on the monthly time scale and a delta approach on the daily time scale; BCCA is an analog scheme. Though *Wilby et al*. [2004] also note that downscaling should rely on variables that are well simulated by the climate model, and one could argue that precipitation is not.

These methods are selected because they are widely used and products are available from a variety of websites (Table 1), and thus there is a need for a review of these methods. For example, *Hay et al*. [2014] used the AR method to look at hydrology and stream temperature changes in future climate. *Brown et al*. [2012] used the BCSD data set produced by *Maurer et al*. [2007] when looking at decision making for water resources. Similarly, *Miller et al*. [2013] used the *Maurer et al*. [2007] BCSD data set when looking at changes in streamflow. *Hanson et al*. [2012] used a modified constructed analog when looking at interactions between surface water and groundwater usage scenarios. Finally, *Brekke et al*. [2009] used the *Maurer et al*. [2007] BCSD data set when evaluating climate change impacts on water resources, as did *Bureau of Reclamation* [2012].

Our primary analyses cover the Contiguous United States (CONUS), but to compare the BCCA and BCCAr approaches, we perform additional analyses over three subdomains (Figure 1). These regional foci are analogous to assessing performance for a water resources study [e.g., *Bureau of Reclamation*, 2012]. The Central Rockies domain can also be compared to a 4 km dynamically downscaled data set [*Rasmussen et al*., 2014], which only exists for this region due to computational constraints.

This paper builds on the literature on evaluation and comparison of downscaling methods. Many previous studies focus on only a single statistical method, often one developed in the same study [e.g., *Salathe*, 2005; *Katz and Parlange*, 1995; *Fatichi et al*., 2011; *Jarosch et al*., 2012; *Ning et al*., 2012; *Pandey et al*., 2000; *Vrac et al*., 2007]. A smaller number of studies have compared multiple approaches, sometimes including dynamical downscaling [*Wood et al*., 2004; *Dibike and Coulibaly*, 2005; *Fowler et al*., 2007; *Maurer and Hidalgo*, 2008;

  

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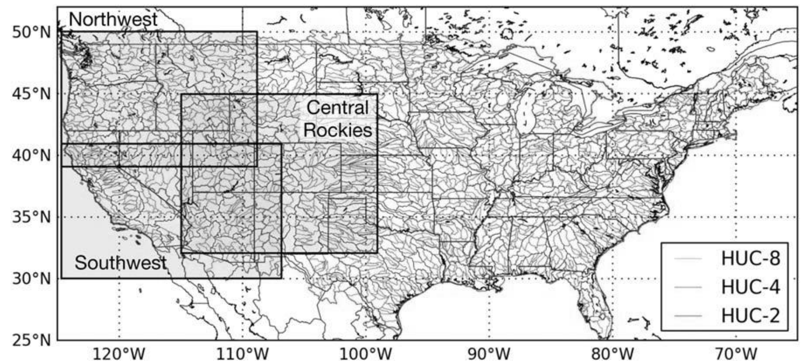


**Figure 1.** Hydrologic Unit Code (HUC) region outlines over the CONUS. Boxes indicate the subdomains used to test the sensitivity of the BCCA method to domain size.

*Chen et al*., 2012; *Gutmann et al*., 2012; *Hwang and Graham*, 2013; *Chen et al*., 2013], though often with only a few statistical validation metrics, e.g., the bias at annual and monthly time scales and, in a few instances, the cumulative distribution function (CDF). Additional metrics such as wet day fraction, extreme event size, or dry spell lengths are often used to validate weather generator type approaches [e.g., *Rajagopalan and Lall*, 1999; *Fatichi et al*., 2011; *Vrac et al*., 2007; *Wilks*, 1998; *Wilby*, 1994; *Mehrotra et al*., 2006], but are rarely used in comparisons of spatially distributed statistical downscaling methods. Particularly unique about the present study is our investigation of the spatial scaling characteristics that are important to hydrology.

This paper is organized as follows: section 2 describes the data sets used in this study; section 3 describes the statistical downscaling methods; section 4 describes the metrics used to assess the output; section 5 describes these results and discusses why each method performs as it does; and section 6 summarizes our findings and provides some suggestions for future research.

## 2. Data Sets

Statistical downscaling methods need a reference data set to calibrate the method, and coarse-resolution model output, which is used in both the calibration and application of the method. The reference data set is typically a fine-resolution gridded observation data set when gridded output is desired, though weather stations are often used for point downscaling. The coarse-resolution model output used is typically from a climate model, but in this case we use a reanalysis data set as a surrogate for climate model simulations that matches historical weather patterns.

### 2.1. Gridded Observational Data Sets

We use the gridded observation precipitation data set of *Maurer et al*. [2002] to calibrate the downscaling methods. To provide additional guidance for the use of various downscaled products, we explore differences between two possible calibration data sets, *Maurer et al*. [2002] and the gridded product of *Livneh et al*. [2013]. Both of these data sets use spatial interpolations from point observations with a topographic adjustment to precipitation similar to that of PRISM (Parameter Regression on Independent Slopes Model) [*Daly et al*., 1994]. Both data sets were designed for climate studies for water resources and incorporate only stations that exist for at least 20 years to minimize homogeneity problems through the record. The Maurer et al. data are on a 1/8° grid (~12 km on a side at midlatitudes) and the *Livneh et al*. [2013] data are on a 1/16° grid (~6 km). Both data sets provide daily values of 24 h accumulated precipitation. Both data sets cover the period from 1949 to 2010, and both data sets primarily cover the CONUS domain used in the present study. Both data sets used approximately 20,000 stations in total, although a maximum of approximately 12,000 stations, which occurred in 1970, were used at any given time [*Livneh et al*., 2013]. This corresponds to, at best, one station for every four grid cells in the *Maurer et al*. [2002] data set, and one station for every 16 grid cells in *Livneh et al*. [2013]. Unless otherwise noted, any mention of "observations" will refer to the *Maurer et al*. [2002] data set. Gridded data sets inherently have some limitations due to the necessary spatial interpolations; however, for distributed applications, gridded data sets are typically required.

  

### 2.2. NCEP/NCAR Reanalysis

We use the coarse-resolution National Center for Environmental Prediction and National Center for Atmospheric Research reanalysis (NCEP/NCAR) [*Kalnay et al*., 1996], henceforth referred to as NCEP product. This product is based on a coarse-resolution atmospheric model similar to that used in a climate model, but it assimilates observations both in the atmosphere and on the surface, and so is representative of current weather. Such reanalyses have been likened to a series of short-term weather forecasts [*Zhang et al*., 2011]. The NCEP data are produced on a 1.9° Gaussian grid (~210 km on a side) comparable to the resolution of many current climate models. This product provides subdaily output, here aggregated to 24 h totals. While the NCEP data cover the period from 1949 to present, we focus on the period containing satellite microwave and infrared atmospheric soundings (1979 on). The NCEP precipitation data are not assimilated, rather precipitation is modeled by the atmospheric model, as it is in a climate model.

## 3. Downscaling Methods

Below we present a brief description of the downscaling methods evaluated with only the critical elements of the methods presented; the reader is referred to the primary relevant literature for details. These methods were calibrated in the period 1979–1999 and applied to both the calibration period and a validation period (2001–2008). All downscaling methods were used to generate daily data, calibrated to the gridded observations.

### 3.1. Bias Corrected Spatial Disaggregation (BCSDm)

The BCSDm method was developed by *Wood et al*. [2004] and is applied in two steps. First, monthly biases in the coarse model are corrected using quantile mapping [*Panofsky and Brier*, 1968] based on observations regridded to the coarse model resolution. Second, the bias-corrected output is spatially disaggregated to the fine-resolution grid by bilinearly interpolating, and then applying a fine-resolution spatial anomaly pattern derived from the observations. The anomaly is calculated as the difference between the fine-resolution observations and the coarsened observations bilinearly interpolated to the fine-resolution grid. These steps are performed at a monthly time step, and daily disaggregation is performed by selecting a semirandom month from the historical period and scaling it to match the monthly total at each grid cell. To select a historical month, the historical months are grouped into the wettest and driest months, and a month is then selected randomly from either the wet or dry months depending on the BCSDm derived monthly total. Variations of this step are possible as discussed in *Raff et al*. [2009]. The BCSDm method is calibrated independently for each month of the year. To prevent anomalously large extreme events, any events that exceed 150% of the observed maximum daily precipitation for a given grid cell are limited to 150% of the observed maximum, and the excess is spread evenly across the rest of that month to preserve the monthly total.

### 3.2. BCSD—Direct Daily (BCSDd)

Recently, the BCSD method has also been performed directly on a daily time step [*Thrasher et al*., 2012]. In this method, the bias correction and spatial disaggregation are both applied to daily coarse-resolution precipitation. This method requires no further temporal disaggregation, and maintains the daily spatial and temporal structure from the coarse-resolution climate model. As a result, this method allows greater modification to the daily precipitation occurrence and intensity distributions in a future climate than the BCSDm method does; however, it also corrects fewer errors in the climate model's spatial representation of precipitation. For example, the bias correction step forces daily climate model wet day fraction to match a corresponding aggregated coarse-scale wet day fraction from the observations, but every fine-scale grid cell within a coarse grid cell will have the same wet day fraction. There is no method to disaggregate wet day occurrence within a coarse grid cell, as a result, if there is precipitation in the coarse grid cell, then there is precipitation at all fine grid cells within that coarse grid cell simultaneously.

### 3.3. Bias Corrected Constructed Analog (BCCA, BCCAr)

The constructed analog method [*Hidalgo et al*., 2008; *Maurer and Hidalgo*, 2008] is derived from traditional analog techniques [e.g., *Glahn et al*., 1972]; however, it constructs a new analog from a linear combination of past dates. To downscale a given date, this method selects 30 analog days from coarsened historical observations that best match the coarse-resolution model spatial pattern of precipitation. Prior to this comparison, we applied a bias correction step to the coarse model output using quantile mapping [*Maurer*

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*et al.*, 2010]. The BCCA method takes these 30 best analog days, calculates the linear combination that would best match the coarse model for that day, then applies that same linear combination to the fine-resolution observations from those 30 days to construct a downscaled analog.

In the BCCA technique, the results are dependent on the entire domain for the analog selection process. As a result, the technique may perform better or worse over regions of different sizes. To test this sensitivity, we apply the BCCA method independently to both the CONUS, as well as to three subdomains (Figure 1, BCCAr) in the Northwest (NW), Southwest (SW), and Central Rockies (CR). In addition, because this method is sensitive to the coarse model representation of weather patterns over a large area, it may have additional problems not examined here when applied to a climate model, which may not simulate the correct spatial distribution of precipitation for individual weather events even on a continental scale.

### 3.4. Asynchronous Regression (AR)

The AR method was first applied to climate data by *Dettinger et al*. [2004] and recently refined by *Stoner et al*. [2012]. In this method, the coarse-resolution model output is bilinearly interpolated to the fine-resolution grid. Next, the time series from the each interpolated grid point, and from the fine-resolution observation data set are each sorted independently from low to high values. Once sorted, the resulting ordered arrays are used as input to a linear regression. *Stoner et al*. [2012] used a piecewise linear regression, where the ordered arrays are subdivided and the regression is performed on each subdivision. We follow that method with six segments spread evenly across the distribution. The result is akin to a quantile mapping performed directly on the fine-resolution grid, but with fewer degrees of freedom. As a result, this method will be similar to BCSD if the order of the BC and SD steps is reversed as in *Hwang and Graham* [2013].

The method is performed independently for each month, with 2 weeks on either side included to increase the effective sample size and allow for shifting seasonality in a future climate as in *Stoner et al*. [2012]. While this may aid in downscaling cooler months in a warmer climate, it is unlikely to help the warmest month. Precipitation regressions are calculated after applying a log transformation to the data. As in *Stoner et al*. [2012], we correct the tails of distribution by capping precipitation with a maximum value, here 120% of the maximum observed value in each grid cell. One hundred twenty percent was selected as intermediate value between the 150% used in the BCSD code, and the published value of *Stoner et al*. [2012], which used 2% above the observed maximum after adding 250 mm to the observed precipitation. Excess precipitation is discarded. While this removal of precipitation does not conservation of mass, it should be noted that none of the downscaling procedures do so; they all rescale precipitation to match observed mean values, and this rescaling both adds mass in some locations and removes it in others with no guarantee of balancing the two. In contrast, conservation of mass and related internal consistency is one of the intrinsic benefits of a dynamical downscaling, it plays no role in the statistical methods evaluated here. For the bottom of the distribution, we do not force the regression of the first segment through zero; however, if the coarse model had no precipitation, the downscaled precipitation was set to zero.

## 4. Evaluation Metrics

Relying only on statistics such as the bias can be misleading in isolation because they potentially mask important spatial and temporal errors in the data. To present a more complete assessment of these statistical products, we present the following additional metrics compared to observations: wet day fraction, wet spell length, dry spell length, interannual variation, extreme precipitation values, and spatiotemporal statistics. Where relevant, our metrics are related to the Climate Variability and Predictability (CLIVAR) Expert Team on Climate Change Detection and Indices (ETCCDI) metrics [*Zhang et al*., 2011], for example, mean annual precipitation is the same as the CLIVAR PRCPTOT metric. Wet day fraction is defined as the fraction of days with precipitation greater than some minimum threshold, similar to the CLIVAR Rnnmm metric, which is the number of days per year in excess of a number (nn) of millimeters of precipitation. Wet (dry) spell lengths are the mean number of days between dry (wet) periods, defined as one or more days with precipitation less (greater) than some threshold, this is similar to the CLIVAR cdd and cwd metrics, which are maximum wet and dry spell lengths. Given the shorter validation time period, we felt that the mean would be a more robust statistic than the maximum. Interannual variation here is simply the standard

  

deviation of annual values. The extreme precipitation and spatiotemporal statistics used are described below. Statistics are calculated at multiple space and time scales as described below.

We assess the impact of methods on extreme events by looking at 1, 2, 3, 4, and 5 day precipitation totals and calculating the 2, 10, 50, and 100 year return interval values. Though 2 and 10 year return interval storms may not be classified as extreme events, they are important for planning purposes. This metric is similar to the CLIVAR Rx1d and Rx5d metrics, which are maximum 1 and 5 day precipitation totals. However, for the relatively short validation period, the maximum values might not be robust. Instead, we calculate the extreme statistics by fitting a gamma distribution to the data [*Katz*, 1999]. We only use the periods in which daily precipitation was greater than 2.54 mm for each grid cell because some of the downscaling methods have excess drizzle, as discussed in section 5.4, and we did not want that to contaminate the fitted distribution. This metric was also calculated using an exponential and a Weibull distribution; while the absolute magnitude of the values differed depending on the type of distribution used, the conclusions reported here were insensitive to the chosen distribution and are not reported separately.

To assess changes in the spatiotemporal patterns between the observations and the downscaled data sets, we use a geostatistical metric, a spatially lagged temporal autocorrelation for each grid cell. The correlation is calculated between the time series of an individual grid cell and that of its neighbors over spatial lags from 12 to 600 km away (1–50 grid cells). This results in fewer samples for coastal grid cells, but they retain the same weight in the final analysis because correlations for a given grid cell are averaged first, next correlations for a given lag distance are averaged across CONUS to produce a correlogram. Differences in space and time with this metric could be significant; however, best geostatistical practices require a domain size that is twice the largest lag distance [*Journel and Huijbregts* 1978], limiting the degree to which we can subdivide the domain.

Hydrologic responses are particularly dependent on issues related to spatial and temporal scales. Responses depend on basin total values in addition to individual grid cell values; hence, we calculate all statistics described above after aggregating precipitation data to hydrologic regions defined by the Hydrologic Unit Code (HUC) [*Seaber et al*., 1987] scales for HUCs 2, 4, and 8 (Figure 1). The HUC-8 scale is only slightly coarser than the resolution of the observations, while the HUC-2 scale is on the order of one quarter of the subdomain. HUC-6 is not used because it is very similar to HUC-4. HUCs 2, 4, and 8 provide approximately an order of magnitude shift in scale between each; there are approximately 50,000 12 km grid cells, 2000 HUC-8s, 200 HUC-4s, and 20 HUC-2s. We use the most recently available HUC data set from the Watershed Boundary Data set (WBD). The WBD is available online at http://datagateway.nrcs.usda.gov [accessed 8 January 2013]. Many applications are also sensitive to the seasonality of precipitation, for this reason, we compute the above statistics for each month as well as for annual values.

As described previously, we apply each of the four methods to the NCEP data sets in both the calibration and validation period. Because wet day occurrence can be important for multiple thresholds, we calculate related statistics using both a 1 mm threshold (as in CLIVAR statistics) and a 0 mm threshold, which is important for some applications. In particular, a 0 mm threshold is used by the MTCLIM microclimate simulator [*Hungerford et al*., 1989] to calculate solar radiation and humidity, which are then used by hydrologic models. While we mention all of these statistics combinations for completeness, we will only present results from the combinations that showed significant differences, additional figures are available in an online supporting information S1.

## 5. Results and Discussion

We focus our results on the validation period, and a summary of common statistics is presented in Table 2. Additional results from the calibration period will be discussed where relevant.

### 5.1. Precipitation Bias

Maps of the mean annual precipitation agree qualitatively with the observations except for the BCCA method (Figure 2). However, substantial spatial biases (>400 mm/yr) are present in some areas (Figure 3) and are consistent with changes in NCEP between the calibration and validation periods (Figure 4). Most methods also match the basic seasonal cycle of mean monthly precipitation (Figure 5). With the exception of BCCA, all methods have more precipitation in May and June and less in January and February. Annually,

  

**Table 2.** Summary Statistics for Each Downscaling Method[a]

| | Mean Annual Precipitation (mm/yr) | Interannual Variation (mm/yr) | 50 yr Return Interval (mm/d) | Wet Day Fraction (0, 1 mm Threshold) | Wet Spell (Days) | Dry Spell (Days) |
|---|---|---|---|---|---|---|
| BCSDm | 805 | 132 | 145 | 0.43, 0.26 | 2.4 | 7.7 |
| BCSDd | 850 | 139 | 109 | 0.88, 0.36 | 4.5 | 5.8 |
| AR | 817 | 161 | 149 | 0.34, 0.24 | 2.1 | 8.1 |
| BCCA | 579 | 101 | 85 | 0.79, 0.27 | 2.0 | 7.4 |
| Observed | 776 | 142 | 140 | 0.39, 0.24 | 2.1 | 7.6 |

[a]All statistics calculated in the validation period (2001–2008) on the individual grid cell level on an annual basis and averaged across the entire (CONUS) domain.

the BCCA method has a substantial dry bias (−197 mm/yr), while all other models are essentially unbiased or have a slightly wet bias (BCSDm: 29 mm/yr, AR: 41 mm/yr, BCSDd: 74 mm/yr). All biases are statistically significant ($p < 0.01$). The largest variation between methods occurs in the late summer months (July–September), when convection is most active. Convection is known to be a very difficult process to parameterize at coarse resolutions [*Randall et al*., 2003; *Weisman et al*., 2008; *Holloway et al*., 2012].

Attributing these biases to the procedures within the downscaling method or to potential discrepancies between the NCEP and gridded observation data sets is difficult. Reanalysis products are not necessarily stationary in time because the observations they incorporate can themselves change over time [*Trenberth et al*., 2011; *Zhang et al*., 2011]. Satellites come and go, as do surface and upper air observations. Of particular relevance, the Advanced Microwave Sounding Unit was first launched on board the NOAA-15 satellite in 1998, prior to 1998 the Microwave Sounding Unit was used to provide global atmospheric sounding input.

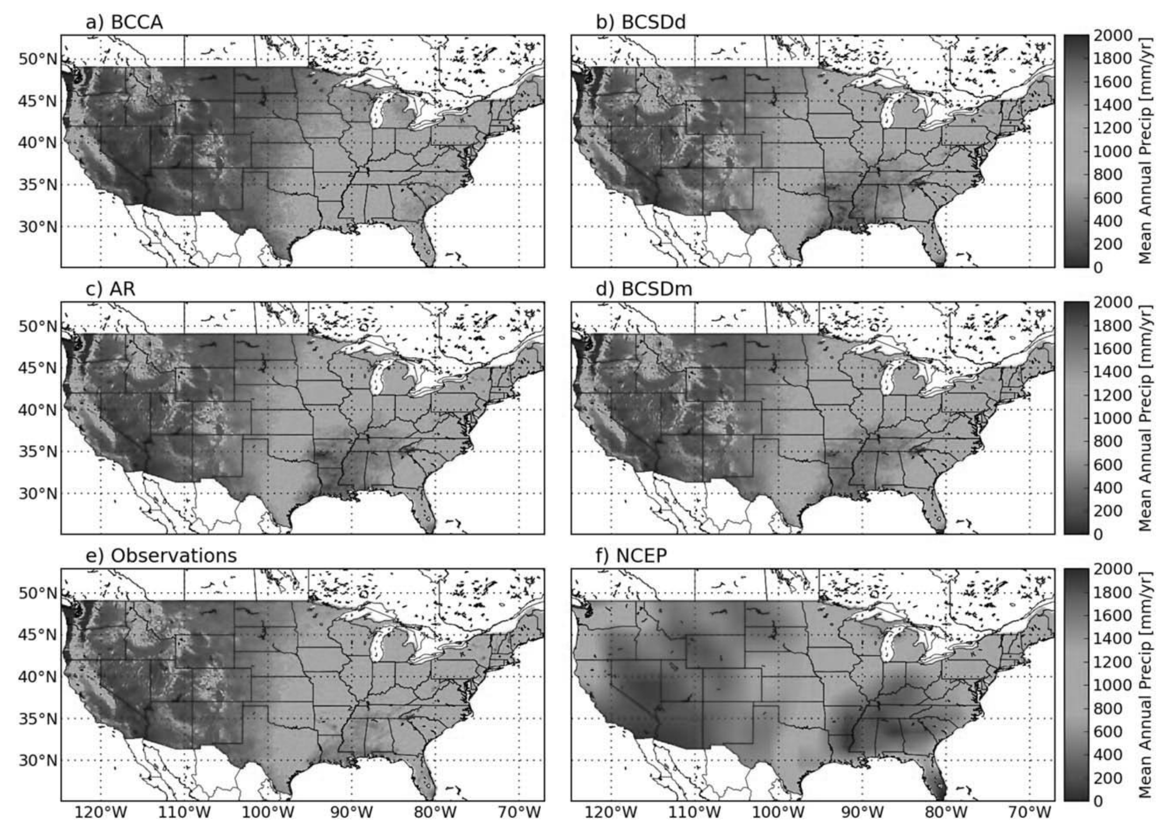


**Figure 2.** (a–d) Maps of mean annual precipitation (mm) simulated by each of the statistical methods, (e) the observations, and (f) NCEP for the period 2001–2008 on a 12 km grid.

  

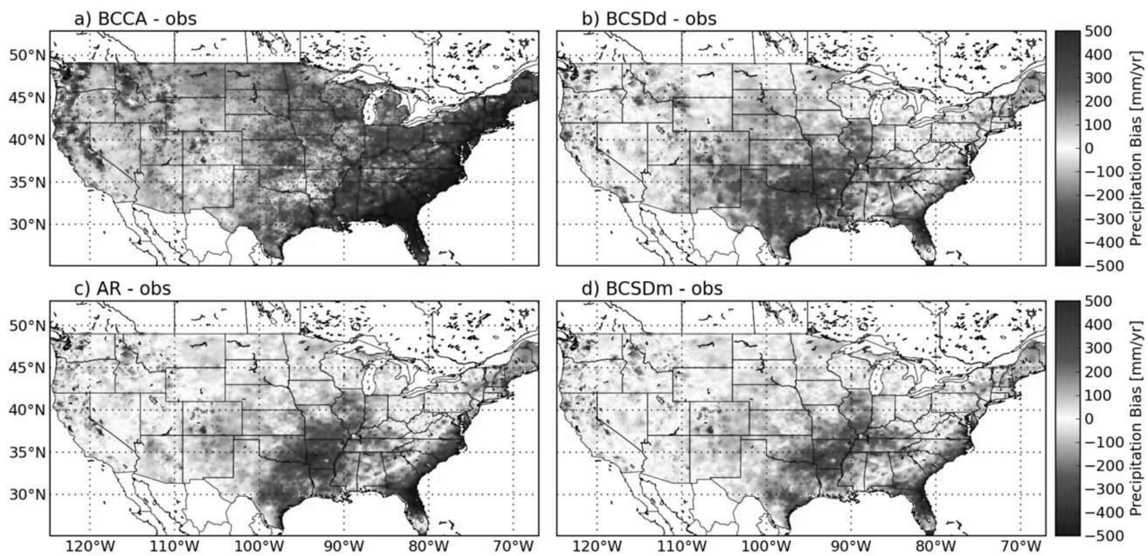


**Figure 3.** Maps of bias in mean annual precipitation (mm) in the validation period (2001–2008) for (a) BCCA, (b) BCSDd, (c) AR, and (d) BCSDm.

This provided a step change in quality of important global atmospheric observations between our calibration and validation periods. Nevertheless, the BCCA method is biased dry even during the calibration period, while other methods are not, which suggests there is a procedural step that results in this bias. BCCAr does not exhibit this bias, instead having a slightly wet bias in each subdomain (NW: 47 mm, SW: 153 mm, CR: 34 mm). *Hwang and Graham* [2013] also found a dry bias in the BCCA method when applied to a smaller region. It is possible that, particularly when fitting a large area, BCCA is likely to select analog days with smoother spatial patterns, resulting in a decrease of larger precipitation events, as discussed in section 5.3, and these larger events will affect mean annual totals substantially.

Comparing maps of bias in the statistically downscaled products over CONUS (Figure 3) with maps of changes in precipitation in the observations and in NCEP (Figure 4) helps suggest an attribution for the bias in some methods. While CONUS-wide biases are relatively minor, the local biases are as large as 400 mm/yr or more and have clear spatial patterns. Because these broad patterns of bias are nearly identical in all methods and match the change in NCEP between calibration and validation periods, it appears that all methods directly inherit mean changes in precipitation from the driving model, and do not correct those changes substantially. It is not clear if those changes are real changes in the mean precipitation between these time periods that is simply represented differently by NCEP and the observations, or if the temporal instability in NCEP data due to variations in ingested data are responsible for the bias.

Similarly, small spatial-scale patterns, for example, the small dry (blue) spot in south central Colorado (37°N, 107°W) in the observation change map (Figure 4), are inversely correlated with the bias maps. While it could

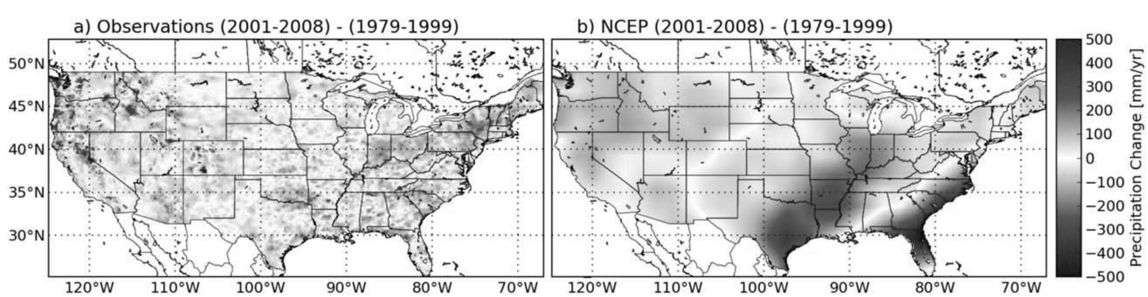


**Figure 4.** (a) Maps of differences in precipitation between the validation and the calibration period for the observations and (b) NCEP.

  

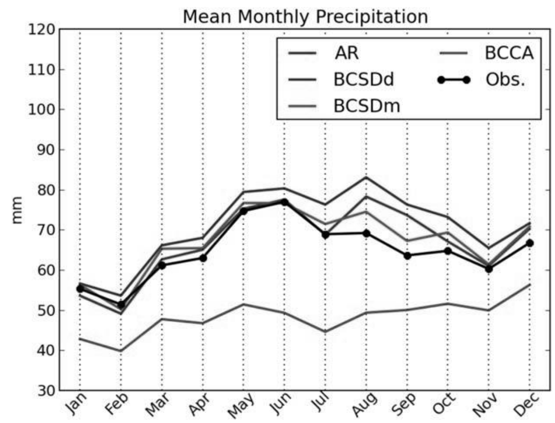


**Figure 5.** Mean monthly precipitation for all methods (colors) compared to observations (black) as averaged over CONUS in the validation period (2001–2008).

be that the local climate has indeed changed over this time period, it seems more likely, given the spatial structure that the observations have changed due to a change in station existence, location, or reporting habits. Lacking any confirmation, this remains a hypothesis in this study; however, observers are human and prone to errors; observer bias in the National Weather Service Cooperative Observer Program network is a known problem, but is difficult to address [*Daly et al.*, 2007].

Finally, the larger biases in the AR and BCSDd methods in August and September (Figure 5) suggest that they may be more sensitive to aspects of the driving model's representation of precipitation. Convective precipitation in particular is the dominant form of precipitation in the summer months in many regions. The chaotic nature of convection and the parameterization required in coarse-resolution models means that convective precipitation may not be well represented in coarse-resolution models. Because the BCSDd and AR methods directly rescale daily coarse model precipitation, they are sensitive to changes in the distribution of precipitation within an individual grid cell. Convection in a coarse model will result in many days with a small amount of precipitation, while the fine-scale observations will have fewer wet days with more intense precipitation. This feature leads to a steep slope in the BCSDd quantile mapping and the AR regression; as a result, minor changes in the coarse models simulation of convection can result in large changes in the downscaled precipitation. The BCSDm method only works with monthly coarse model precipitation directly, while the two BCCA methods are not as sensitive to individual grid cells because they fit an analog over a larger region.

### 5.2. Interannual Variability

Maps of the interannual variability are presented in Figure 6. These maps show that all downscaling methods improve interannual variability spatial patterns in the western United States, where large mountain ranges play a key role in the spatial variability of precipitation. However, in the south central and eastern United States, the spatial patterns of the downscaled interannual variability are correlated better with spatial patterns in NCEP than in the observations. In addition, the BCCA method is biased low (101 mm/yr) compared to the observations (142 mm/yr). The BCSD methods are largely unbiased (BCSDm: 132 mm/yr, BCSDd: 139 mm/yr), while the AR method is biased slightly high (166 mm/yr). The seasonal cycle of interannual variability is roughly captured by all methods (Figure 7), although the BCCA has too little seasonality; the AR has increased variability in July, August, and September; and the two BCSD methods are biased low for individual months even though their variability on an annual scale is unbiased. Interannual variation in monthly precipitation does not necessarily aggregate to interannual variation in annual totals because wet and dry months may offset each other in a given year.

Interannual variation is not explicitly corrected by any of the downscaling techniques, and so is essentially inherited directly from the driving coarse-resolution model and is only substantially modified by any scaling provided by the downscaling for mean precipitation. This is particularly evident in the patterns of spatial variability (Figure 6). For example, the mountains in the western United States show increased interannual variability in the downscaled products relative to NCEP, this can easily be explained by the fact that total precipitation in the mountains has to be scaled up considerably. The increase in interannual variability in the AR method in the summer months (Figure 7) appears to be similar to the increased errors in the bias during this time period. We hypothesize that this is again due to issues with scaling summer convection. BCCA is biased low simply because its mean annual precipitation is biased dry, when interannual variability is normalized by mean annual precipitation BCCA is relatively unbiased.

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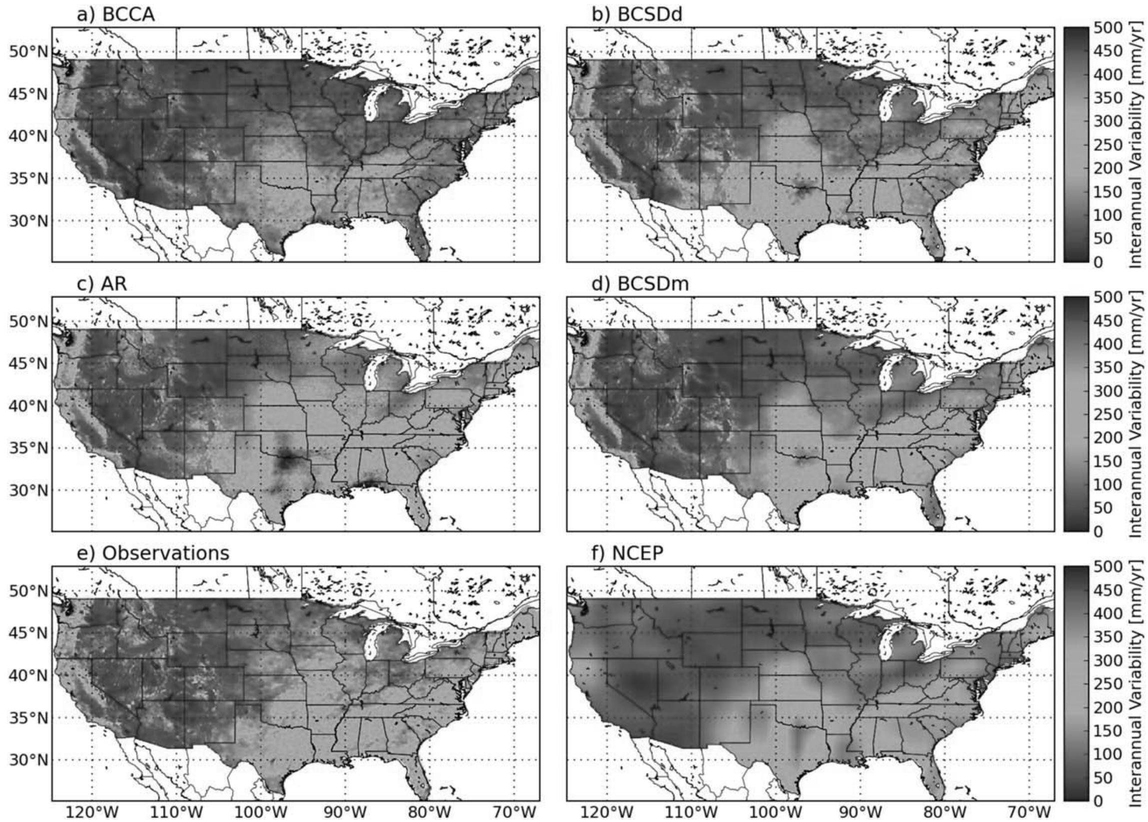


**Figure 6.** (a–d) Maps interannual variability during the validation period (2001–2008) as represented by the standard deviation of annual precipitation for all methods, (e) observations, and (f) NCEP.

### 5.3. Extreme Events

We assess the representation of extreme events by presenting the 50 yr return interval for a 1 day event across spatial scales (Figure 8). Results are similar for the 2, 10, and 100 yr return interval storms and for 2–5 day event totals (supporting information S1). The BCCA method substantially underestimates the more extreme precipitation values (70 mm/d versus 136 mm/d for observations) especially at the grid cell scale. The BCSDm method is relatively unbiased (140 mm/d) and changes properly as a function of scale. The AR method is biased slightly high (149 mm/d) at the individual grid-cell scale; however, it does not change correctly when aggregated to coarser scales and is biased higher at all larger scales. The BCSDd method is biased low at the grid cell scale (90 mm/d). All values are significantly different from observations ($p < 0.01$). In addition, BCSDd does not change appropriately as a function of scale. As a result, BCSDd is unbiased at the coarsest scale. The same general pattern is evident over the subdomains (Figure 8), but here we can compare BCCAr as well. BCCAr is exhibits different biases in each subdomain (NW:

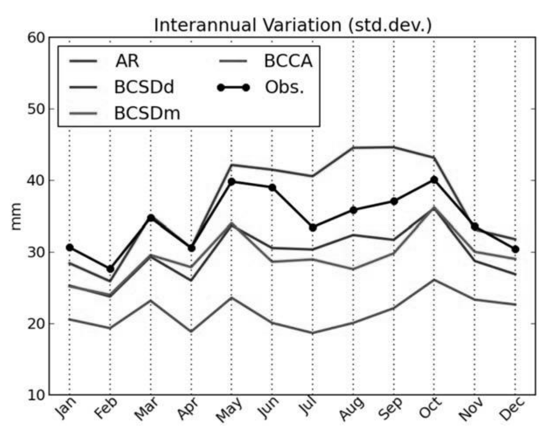


**Figure 7.** Seasonality of interannual variability of monthly totals for all methods (colors) compared to observations (black) as averaged over CONUS in the validation period (2001–2008).

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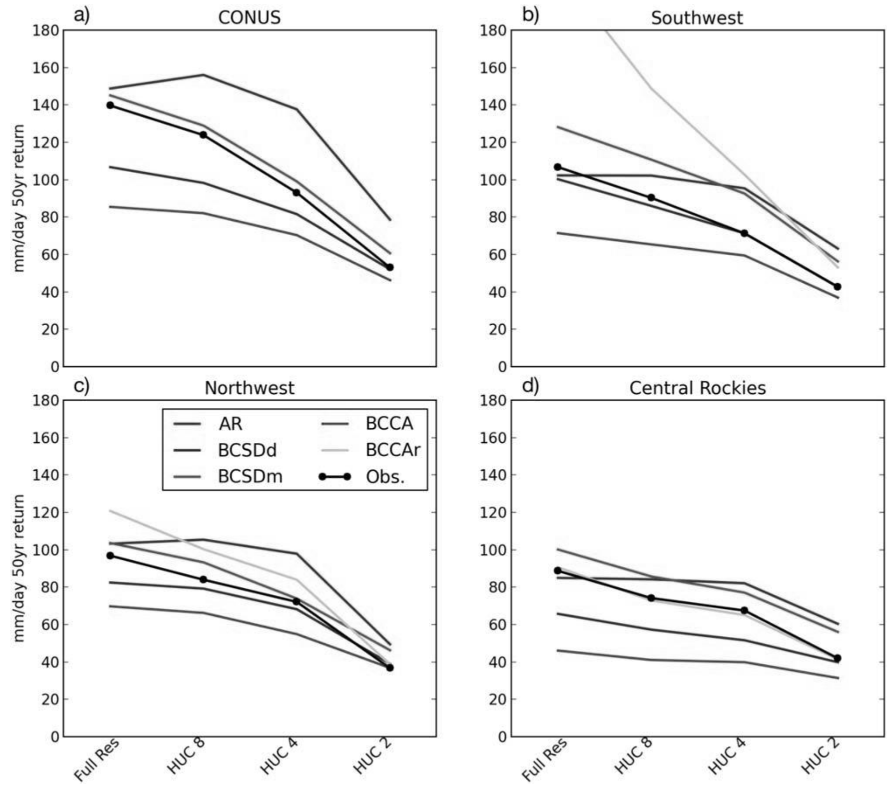


**Figure 8.** (a) Change in representation of extreme events across scales for all methods (color) and observations (black) averaged over CONUS and (b–d) the subdomains in the validation period (2001–2008).

24 mm/d, SW: 105 mm/d, CR: 2 mm/d) at the grid cell scale though it scales more appropriately than BCCA in all regions. BCCA is biased low in all subdomains. Interestingly, BCSDd exhibits smaller biases in the Northwest (−14 mm/d) and Southwest (−6 mm/d) subdomains, while BCSDm is biased high (21 mm/d) in the Southwest subdomain and, to a lesser extent, in the Central Rockies subdomain (11 mm/d).

The BCSDd and AR methods both directly scale the coarse-resolution precipitation, thus, when an extreme event occurs in the coarse-resolution model grid cell, an extreme event will occur at every downscaled grid cell within that coarse-resolution grid cell. In reality, the largest storm basin average will be spatially heterogeneous within the basin. This creates the spatial scaling problems in these methods. In contrast, the BCSDm method selects an arbitrary day in the past, which will have a realistic pattern of spatial variability. However, when rescaling that precipitation, it can lead to local biases as seen when averaging over smaller areas in the subdomains in BCSDm, while AR is more consistent across subdomains.

Similarly, the BCCAr method changes scale more reliably than AR (Figure 8) because it uses real spatial patterns from the past. The dry bias in BCCA occurs because fitting a precipitation map over a large area will tend to select smoother fields as analog days. Compounding this problem, the BCCA method averages multiple analog days together to construct a new analog; as a result, it will inherently smooth out spikes, which might be present in some analog days, or may be in different (subgrid) locations in each of the analogs. However, over small regions, BCCAr can have nearly as many coarse model grid cells (∼50) to fit as it has degrees of freedom (30 analogs), as such it can easily overfit the coarse model output and end up with unrealistic scaling artifacts. For example, on 1 day during the calibration period for the Southwest domain, BCCAr had a weight of −42 applied to one analog and a compensatory weight of +44 applied to another analog, analog weights are expected to sum to a value near 1 and are typically between 0 and 1. At the coarse resolution, these weights result in a near perfect fit to the coarse model, but these two analogs did not have precipitation on the same fine-scale grid cells, as a result precipitation magnitudes in excess of 1000 mm/d were generated, negative values were discarded.

  

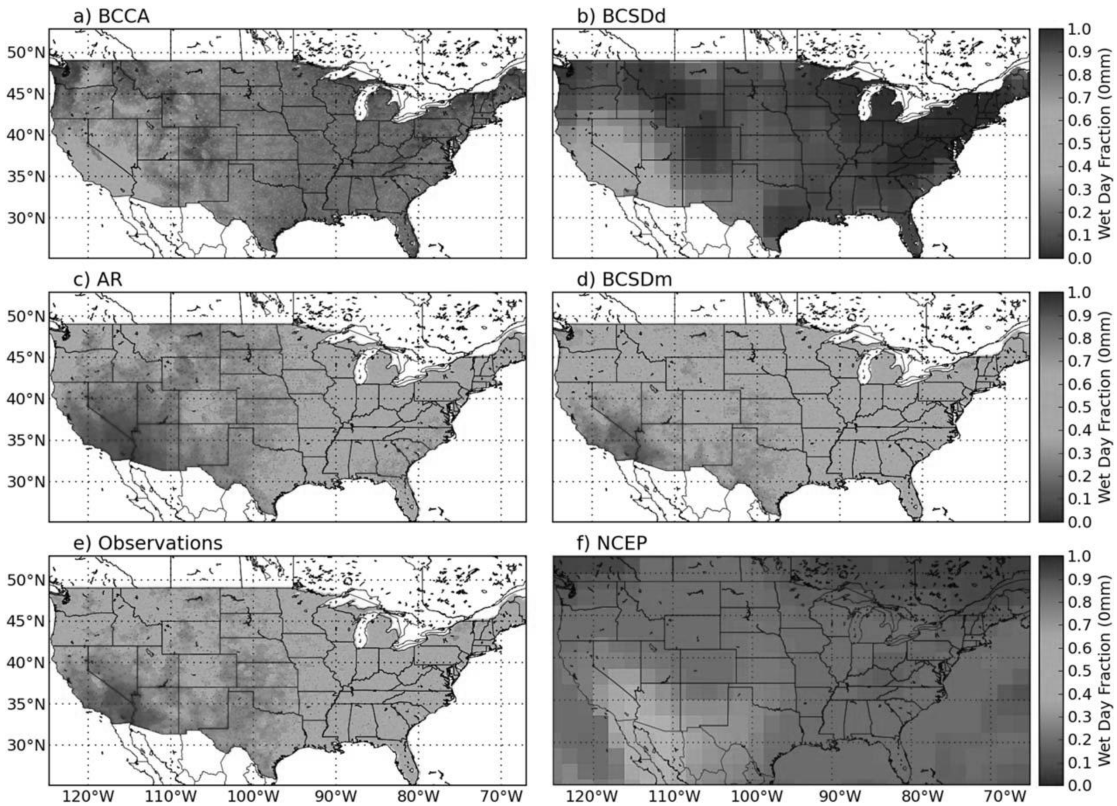


**Figure 9.** (a–d) Wet day fraction (0 mm threshold) maps from all methods (e) observations and directly from (f) NCEP in the validation period (2001–2008).

The BCSDd method tends to produce extreme values that are too small at the individual grid cell level because the most extreme days are only bias corrected at the coarse model grid-cell scale. When these coarse-resolution data are disaggregated to each individual grid cell, the BCSDd method is unable to recreate local hot spots of precipitation necessary to recreate extreme events. However, as the spatial averaging domain is increased to a scale comparable to the coarse grid cell, that evenly distributed event aggregates into a fairly extreme event over the entire basin. Of note, in some subdomains these local hot spots are less important, as a result, BCSDd performs better.

### 5.4. Wet Day Fraction

Wet day frequency is important when downscaled data are used as input to hydrologic models. Precipitation occurrence is used as a predictor in hydrologic models that use an algorithm similar to MTCLIM [*Hungerford et al*., 1989] to calculate solar radiation as in the Variable Infiltration Capacity (VIC) model. Specifically, solar radiation is decreased to 75% on wet days. Precipitation occurrence is also used when calculating humidity with MTCLIM. As a result, biases in wet day fraction can severely affect evapotranspiration calculations in such models. Here we show results both from the 0 mm threshold used in MTCLIM and the 1 mm threshold defined by CLIVAR as a wet day.

To illustrate methodological performance at reproducing wet day fractions, we present maps for all methods with a 0 mm threshold (Figure 9), as well as a plot of mean wet day fraction as a function of scale for both a 0 and 1 mm threshold (Figure 10). Large biases exist in the BCCA and BCSDd methods representation of wet day fraction particularly for the 0 mm threshold, and our initial discussion focuses on the 0 mm threshold. The observed wet day fraction is 0.39, while the BCCA and BCSDd methods are biased high (0.79 and 0.88, respectively). The BCSDm method is biased slightly high (0.43) while the AR method is biased slightly low (0.34). BCCAr improves slightly compared to BCCA. All values are significantly different from observations ($p < 0.01$).

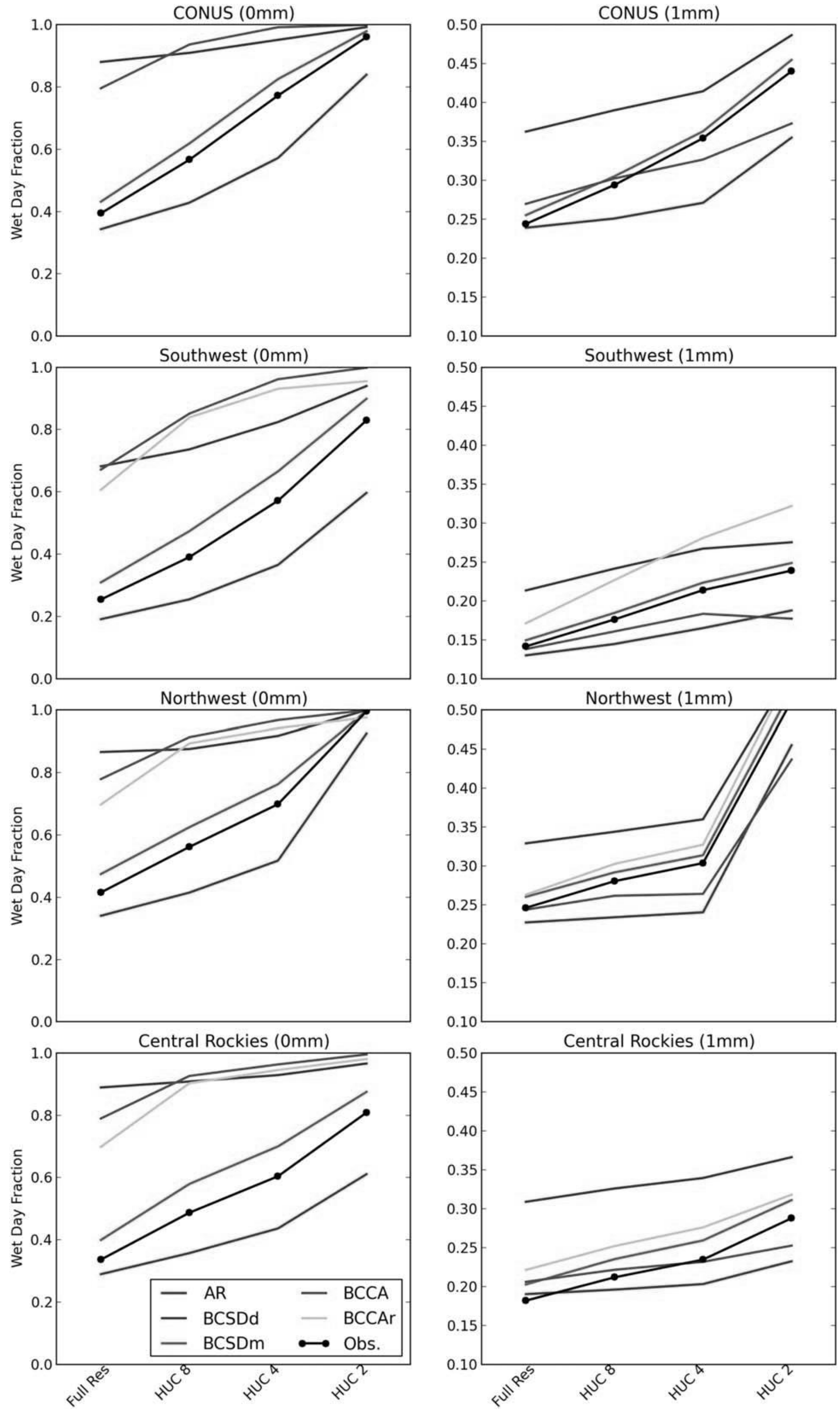


**Figure 10.** (top) Wet day fraction as a function of spatial scale over the CONUS and (bottom) subdomain for each of the five statistical methods downscaled from NCEP (colors) and the 12 km observed product (black) in the validation period (2001–2008). (left) Calculated using a 0 mm threshold, and (right) a 1 mm threshold.

  

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Maps of wet day fraction show substantial spatial structure, most notably, the BCSDd method retains the original NCEP grid structure with only very slight modifications. This grid structure remains because the BCSDd method primarily changes wet day occurrence at the coarse model grid scale, while local values are simply scaled from that coarse model grid cell. In contrast, the BCCA and BCSDm methods resample the historical record and thus obtain spatially variable wet day occurrence. The AR method shows a hint of the NCEP grid structure, for example, there is a vertical line step change at 35°N, 110.5°W, but because it can modify wet day occurrence at the fine grid cell level, it is able to produce realistic variability.

Both BCSDd and the BCCA methods substantially overestimate the wet day fraction at all spatial scales with a 0 mm wet day threshold (Figure 10). For the same reasons that BCCA methods do not produce large extreme events (smoothing of the precipitation field), they also produce too much drizzle. The BCSDd method has two features leading to its increased wet day fraction. First, performing the bias correction step at the coarse model grid scale leads to more wet days than any fine-resolution grid cell would have on its own. This happens because when any fine-resolution grid cell has precipitation, the aggregated coarse grid cell will be forced to have precipitation. When the observations are aggregated to the NCEP grid, many locations have wet day fractions $>0.9$. Second, the bilinear interpolation step increases drizzle because when any of the four surrounding coarse model grid cells have precipitation, every fine grid cell between them will have some amount of precipitation and the spatial disaggregation step will not substantially decrease wet days in fine-resolution grid cells. The AR method avoids similar problems by fitting the precipitation intensity distribution for each fine-resolution grid cell independently. However, it does not properly scale wet day fraction (Figure 10). When precipitation does occur, the AR method typically spreads wet and dry days across an entire coarse grid cell at once, and thus it does not substantially increase the wet day fraction when aggregated to coarser scales.

The BCSDm method is largely immune to problems reproducing wet day frequency because it resamples data from the historical record and only scales the results. However, the BCSDm method will add new wet days to mitigate problems with extreme events. If one of the rescaled precipitation values exceeds 150% of the observed maximum precipitation, the excess precipitation is spread evenly across the remaining days in the month. This preserves the monthly total precipitation and prevents artificially large extreme events from being created, but it leads to a small increase in the wet day fraction. This resampling of the historical record also means that BCSDm cannot change the wet day fraction in future climate even if climate models suggest it should.

The use of a 1 mm threshold, instead of 0 mm, to define a wet day improves the results for the BCCA and BCSDd methods (Figure 10). The observed wet day fraction is 0.24; BCSDd is still biased high (0.36), while the AR method is unbiased (0.24) and the BCCA and BCSDm methods are biased slightly high (0.27 and 0.26, respectively). All differences remain statistically significant ($p < 0.01$). The AR method and the BCSDm method both behave the same as the observations to changes in the threshold used because they match the histogram of the observations (supporting information S1). The scaling behavior of all of these methods is also unchanged when using the 1 mm threshold (Figure 10), but because BCCA has less bias at the grid-cell scale, it ends up biased low at scales greater than HUC-8 because it still does not change scale correctly. BCCAr exhibits a better scaling relationship when using a 1 mm threshold, because it is no longer close to the physical upper bound and thus can increase with scale (Figure 10).

**5.5. Wet/Dry Spell Length**

Hydrologically, increased wet spell lengths can result in wetter soils during rain events and more runoff, increased dry spell lengths can result in drier soils, plant stress, and more demand for irrigation. Here we use a 1 mm threshold to determine wet and dry spell lengths because the MTCLIM threshold is not relevant. The observed average wet spell length is 2.1 days; the BCCA (2.0), BCSDm (2.4), and AR (2.1) methods are relatively unbiased, while the BCSDd method has a substantial high bias (4.5 days). The observed dry spell length is 7.6 days, BCCA (7.4), and BCSDm (7.7) have very little bias, while BCSDd (5.8) is biased low, and AR (8.1) is biased high.

Reproducing the seasonal cycle of wet and dry spell lengths is more challenging for these methods (Figure 11). Wet spell length is nearly unchanged over the year in the observations with a slight peak in May, but the BCCA and AR methods have a maximum in August. The BCSDd method has far too strong a seasonality

  

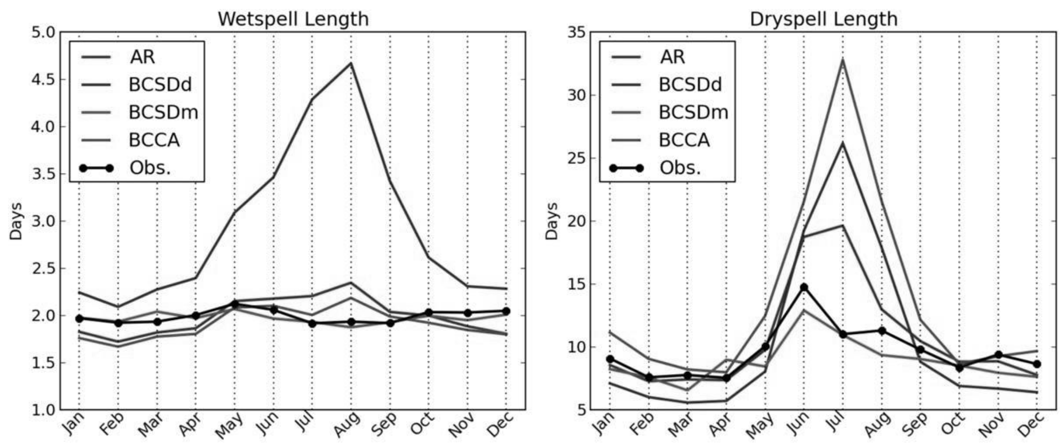


**Figure 11.** (left) Seasonality of wet spell length and (right) dry spell length for each of the statistical methods downscaled from NCEP (colors) and the 12 km observed data set (black) as averaged over CONUS in the validation period (2001–2008).

with a large peak in August, while the BCSDm method exhibits approximately the correct seasonality. The biases in BCCA and AR are unlikely to substantially affect most applications; however, the BCSDd high bias from May to September may have consequences for hydrologic or agricultural applications.

There is a stronger seasonal cycle in the observed dry spell length, and BCSDm is the only method that roughly matches it. The observed cycle shows an increase in May and June that slowly decreases through the year. BCCA, BCSDd, and to a lesser extent AR, all overestimate the seasonal cycle. The AR method overestimates the peak dry spell length in June and July, but is close to the observations for the remainder of the year. We hypothesize that this change in June, July, and August is likely due to problems with the convective parameterization as discussed in the section on bias in mean annual precipitation. The skill of BCSDm in both these metrics may signify a problem in future climate simulations, where it is unable to increase or decrease wet and dry spell lengths, although that may be preferable to potentially tripling the mean dry spell length by using BCCA in July.

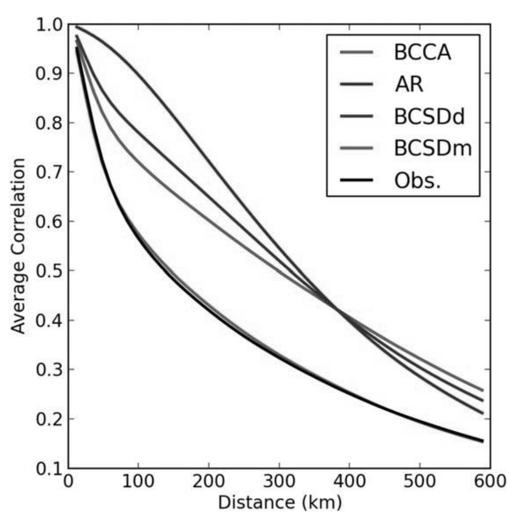


**Figure 12.** Spatiotemporal autocorrelations for all methods (colors) and observations (black) as computed over CONUS in the validation period (2001–2008).

### 5.6. Spatiotemporal Statistics

The geostatistical properties of precipitation are important hydrologically because runoff accumulates over a basin. Spatiotemporal autocorrelograms (Figure 12) reveal that the BCSDm method simulates the geostatistical features of the observations better than other methods, with correlations decreasing sharply from 0.95 to 0.55 over 100 km of separation. All other methods over estimate spatiotemporal correlations for all lag distances. When applied to NCEP, at a lag of 100 km, the AR method has the strongest correlation (>0.9), followed by BCSDd (0.8) and BCCA (>0.7). For lags longer than 400 km, approximately the width of two NCEP grid cells, this relationship is reversed, with the BCCA method having larger correlations and the AR method having lower correlations; all three remain higher than the observations or the BCSDm method. Because the BCSDm method does not attempt to match daily patterns from the driving coarse model, it

  

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**Table 3.** Comparison of Summary Statistics Between Observation Resolutions[a]

| | 50 Year Return Interval (mm/d) | Wet Day Fraction | Wet Spell (Days) | Dry Spell (Days) |
|---|---|---|---|---|
| 6 km | 107 | 0.49 | 4.4 | 9.2 |
| 12 km | 140 | 0.39 | 2.1 | 7.6 |

[a]All statistics calculated in the validation period (2001–2008) on the individual grid cell level on an annual basis and averaged across the entire (CONUS) domain, wet day fraction calculated with a 0 mm threshold.

maintains the correct geostatistical properties across all scales.

### 5.7. Observation Data Set Resolution

We assessed the effect of the resolution of the observation data set using the same metrics discussed previously, and there are significant differences between the 6 km and the 12 km observation data sets (Table 3). Although the mean annual precipitation totals were roughly the same, the 6 km data set had a higher wet day fraction (0.49) compared to the 12 km product (0.39), longer wet spell lengths (6 km: 4.4 days, 12 km: 2.1 days), but also slightly longer dry spell lengths (6 km: 9.2 days, 12 km: 7.6 days). Similarly, the 6 km data set had smaller extreme events; the average 50 yr return interval single day storm totals for the 6 km data set was 102 mm/d, and for 12 km it was 140 mm/d.

These differences are notable because they do not correspond with expected changes. In particular, finer resolution precipitation data sets should be expected to have lower wet day fractions with corresponding shorter wet spell lengths because the probability of precipitation occurrence will be lower for smaller areas, while in a large grid cell there is a higher probability of precipitation occurring somewhere within that grid cell. Finer resolution data sets should also have larger extreme events because these events have not been averaged across a larger area that would be likely to have some areas with less precipitation. While both of these statistics change in the opposite direction from what they should, the changes are not surprising given the methods used to generate these data sets. These data sets are generated by interpolating data between point observations. By interpolating over more grid cells, as is required in the 6 km data set, wet days will typically be added. Similarly, extreme events will typically be strongest in the grid cell containing the observation, and decrease in grid cells where it is interpolated to lower values between observations. Similar issues in gridded data sets were noted in *Gervais et al*. [2014].

Such interpolation artifacts are clearly evident in maps of wet day fraction (0 mm threshold) for the two data sets (Figure 13). These maps have a polk-a-dot appearance, where the dots are located on grid cells that contain station data. This polk-a-dot appearance is strongest in the 6 km product because there is a higher ratio of grid cells to observation points. Figure 13 shows the subdomain to make it easier to see spatial features, but the same patterns are seen across the CONUS. The artifacts described in this section are carried through to any downscaled products based on these data sets. For end-users, these artifacts must be balanced against the added utility of a finer resolution product that is able to better represent important topographically controlled spatial heterogeneity, e.g., colder temperatures and more precipitation at higher elevations.

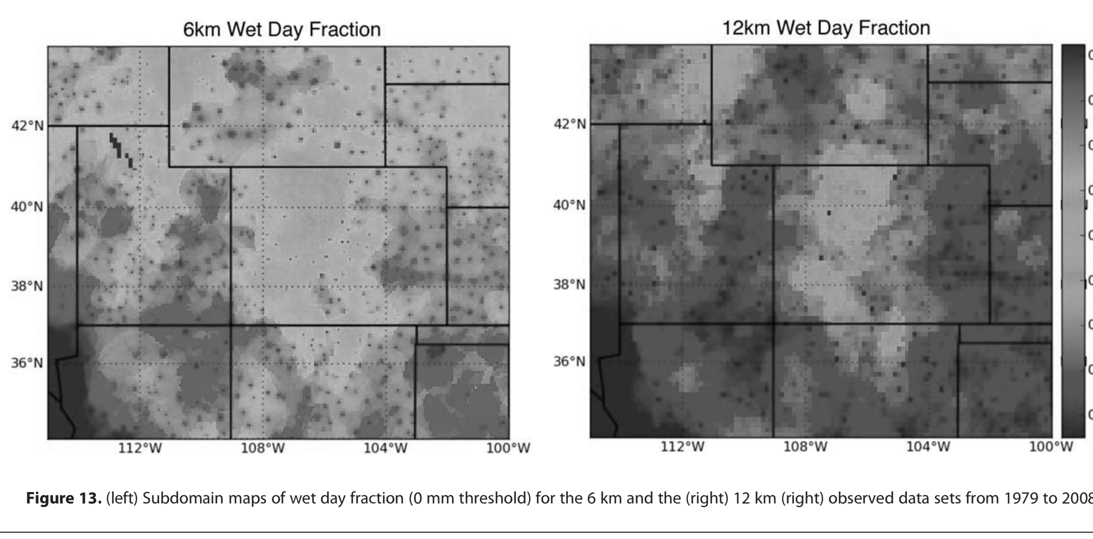


**Figure 13.** (left) Subdomain maps of wet day fraction (0 mm threshold) for the 6 km and the (right) 12 km (right) observed data sets from 1979 to 2008.

  

## 6. Conclusions

We have presented a comprehensive overview of the performance of four common statistical downscaling methods for the CONUS using a suite of hydrologically relevant measures. These methods were compared to observations in both a validation and calibration period, as applied to the NCEP/NCAR Reanalysis product. Methods were compared by analyzing the bias in means, extreme events, wet day fraction, and wet/dry spell lengths. These comparisons were performed for annual and monthly totals across spatial scales ranging from individual 12 km grid cells to Hydrologic Unit Code (HUC) 8, 4, and 2 regions. This increases our knowledge of one of the major sources of uncertainty in climate simulations identified by *Vano et al*. [2014].

Some important distinctions can be drawn to aid researchers and water resource managers. The BCCA technique applied at a continental scale has some serious deficiencies with a dry bias, decreased extreme precipitation values, and substantial increases in drizzle as was found in *Hwang and Graham* [2013]. Performance on all of these metrics is improved when it is applied on a regional basis (BCCAr), though in some regions BCCAr overestimates extreme events substantially. BCSDd is essentially unbiased, but has problems with increased drizzle and smaller magnitude extreme events. The AR method does well in most statistics at the individual grid-cell scale; however, it produces extreme events that are too large, and too few wet days when aggregated to larger scales as expected by *Maraun* [2013]. The BCSDm technique introduces the fewest artifacts in current climate, but is limited in how much it can change in a future climate compared to other methods because it resamples a month of historical weather at a time, thus limiting its ability to reproduce changes in storm frequency or type in the future. This may also result in discontinuities in the weather sequence between months, which could have negative consequences for some applications. Finally, no method substantially modifies interannual variability; all methods inherit the coarse model interannual variability and only scale it slightly as a side effect of scaling precipitation totals. While temporal instability in the reanalysis and observational products are noted and affect the estimates of bias in all but BCCA, all of the other metrics produce the same results in both the 10 year validation and the 20 year calibration periods, showing that these instabilities do not affect our conclusions, nor does the length of the testing period.

In addition, none of these methods will capture changes in spatial patterns as illustrated in *Gutmann et al*. [2012]. All of the current methods contain assumptions of stationarity in the fine-scale spatial patterns, and thus may have other problems when applied to a climate change scenario. This assumption is likely stronger in methods such as BCSDm, which relies historical weather patterns and sequences directly, than in methods such as BCCA, which construct new spatial patterns. Stationarity assumptions are difficult to assess, but recent work by *Dixon et al*. [2013] provides one approach to the problem.

One additional result of this study is the finding that the 6 km observed precipitation product introduces artifacts when compared to the 12 km product. The additional interpolation required leads to a larger number of wet days, and smaller magnitude of extreme events. Future work needs to improve finer resolution observational products, possibly incorporating spatial variations from radar data or a weather model, but doing so without introducing homogeneity problems in the record is difficult.

The paper is deliberately limited in scope to assess statistical downscaling methods used in some cases to support studies for long-term water resource planning [*Brekke et al*., 2011]—the methods examined in this paper are all based, in one way or another, on rescaling coarse model precipitation, and we do not consider the broader class of statistical downscaling methods, see *Wilby et al*. [1998] or *Fowler et al*. [2007] for a review. The downscaling approaches reviewed here may actually violate a fundamental tenet of statistical downscaling, that is, to use variables reliably simulated by the climate model in a statistical model to provide information at local scales [*Benestad et al*., 2008]. However, these methods require evaluation because of their widespread use [*Barsugli et al*., 2013]. Ongoing work considers methods that make extensive use of information on atmospheric circulation patterns [e.g., *Clark and Hay*, 2004; *Bárdossy and Pegram*, 2011], and computationally efficient precipitation models as in *Jarosch et al*. [2012]. Future work will also look at how different methods modify the climate change signal produced by a climate model; fidelity in current climate does not guarantee a good representation of future climate.

**Acknowledgments**

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RECLAMATION

*Managing Water in the West*

# Using Climate Projections in Hydrologic Analysis:

# Which projections? Which aspects? Issues with Low-Frequency Variability

Levi Brekke (Reclamation, Technical Service Center)

Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management

13-15 January 2010, Boulder, CO

U.S. Department of the Interior
Bureau of Reclamation

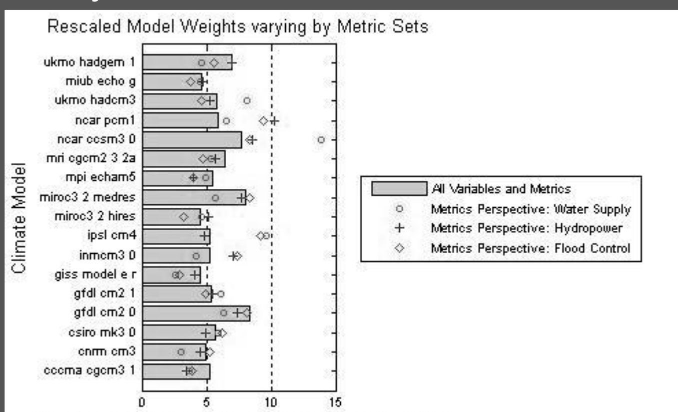
Should we focus on some projections and throw out others?

Does this choice affect portrayal of climate change uncertainty?

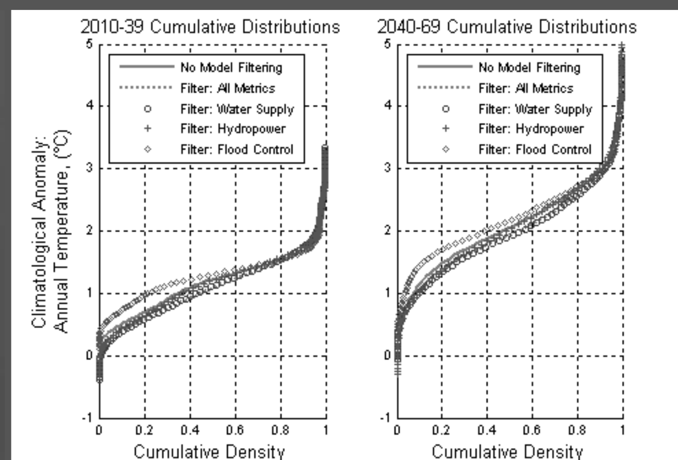
RECLAMATION

# It's easy to cull… but it may not matter… and the case isn't closed.

Focusing on CA, Brekke et al. (2008) considered "historical" simulations from 17 GCMs, and found similar skill when *enough* metrics were considered. Focusing globally, Gleckler et al. 2008 and Reichler et al. 2008 found similar results.



Weights sum to 100, and are based on Euclidean distance between Reference and model, along standardized metrics




Focusing on CA, projection distributions didn't change much when the GCM-skill assessment (Brekke et al. 2008) was used to reduce the set of 17 GCMs to a "better" set of 9 GCMs.

Santer et al. *PNAS* 2009 – results from a global water vapor detection and attribution (D&A) study were largely insensitive to skill-based model weighting. Pierce et al. *PNAS* 2009 – results from western U.S. D&A study were more sensitive to ensemble size than skill-based model weighting.

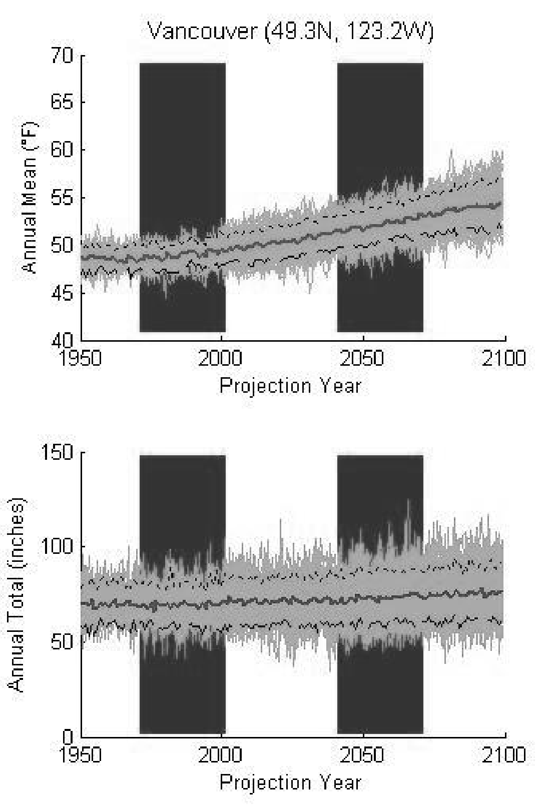
# Use which projection aspects?

Time-evolving? (e.g., moving statistics, changing frequency of drought or surplus potential)?

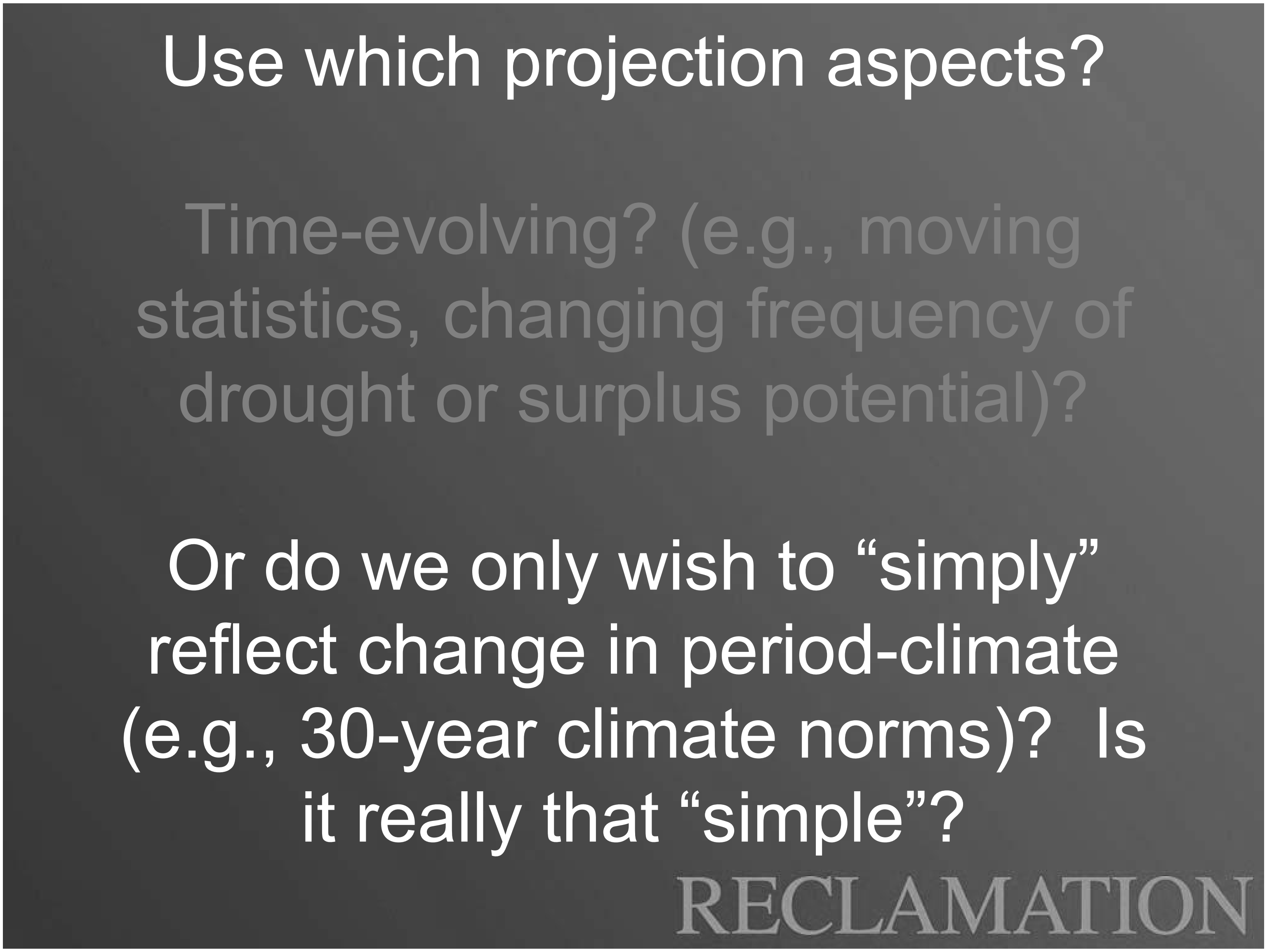
Or do we only wish to “simply” reflect change in period-climate (e.g., 30-year climate norms)? Is it really that “simple”?

RECLAMATION

# **Time-Developing** view (…and use of Climate Projection Ensembles)



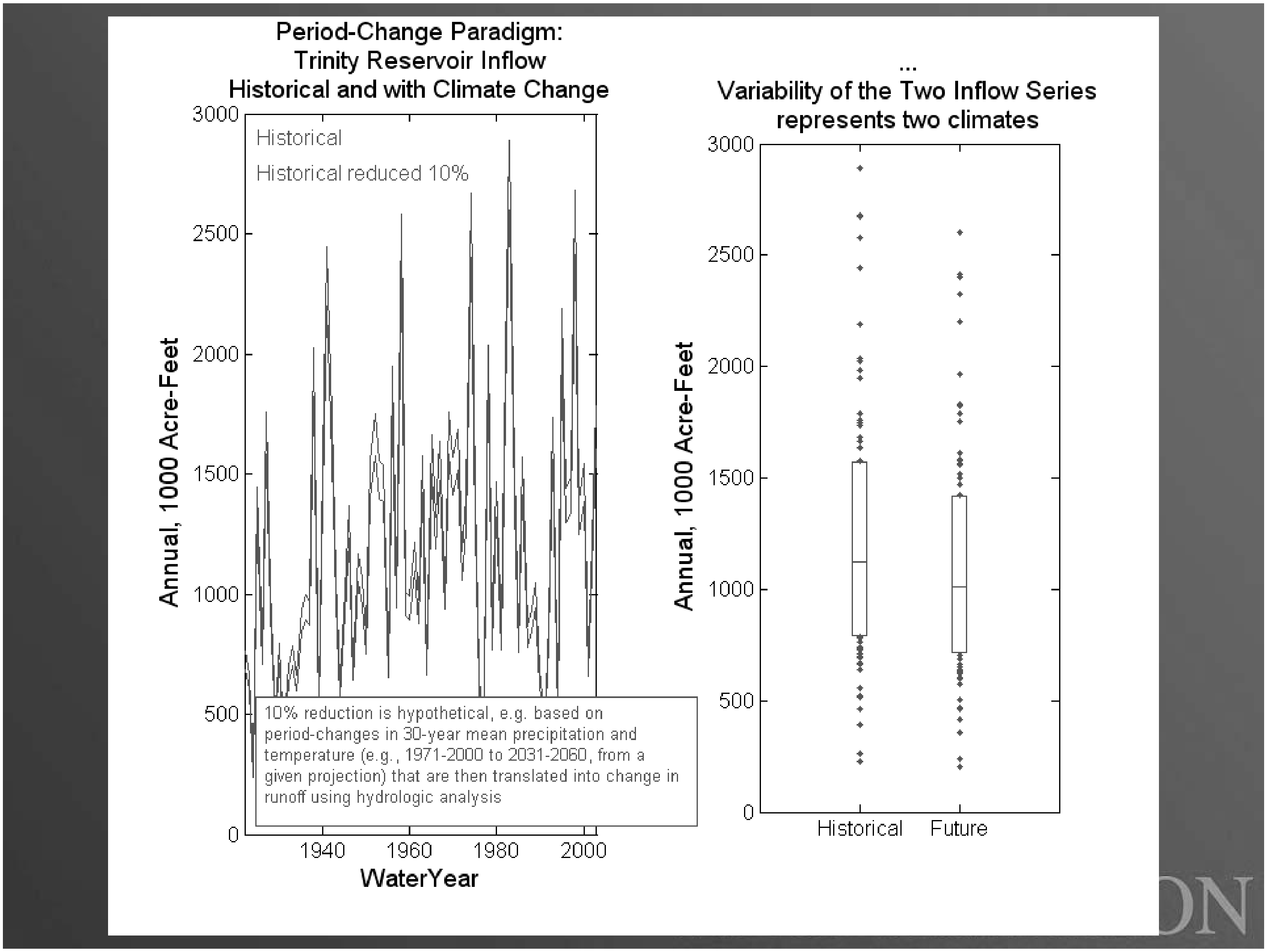

RECLAMATION


Use which projection aspects?
Time-evolving? (e.g., moving statistics, changing frequency of drought or surplus potential)?
Or do we only wish to “simply” reflect change in period-climate (e.g., 30-year climate norms)? Is it really that “simple”?
RECLAMATION

# Water Resources Study: Period-Change Example

- Goal: characterize hydrologic impact under climate change
- Approach:
  - Climate change = change in 30-year climate
  - Assess period-change hydrology response
  - Relate period-change hydrology to inflow adjustments in our operations models…
  - Analyze operational impacts…

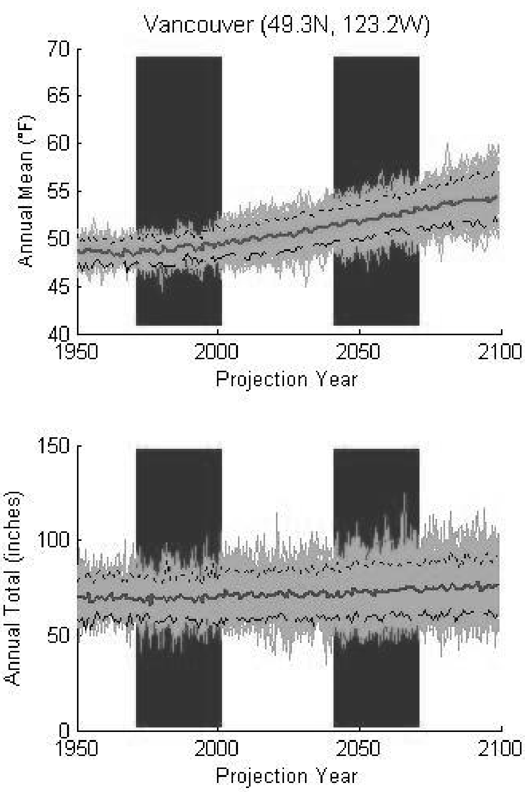
RECLAMATION

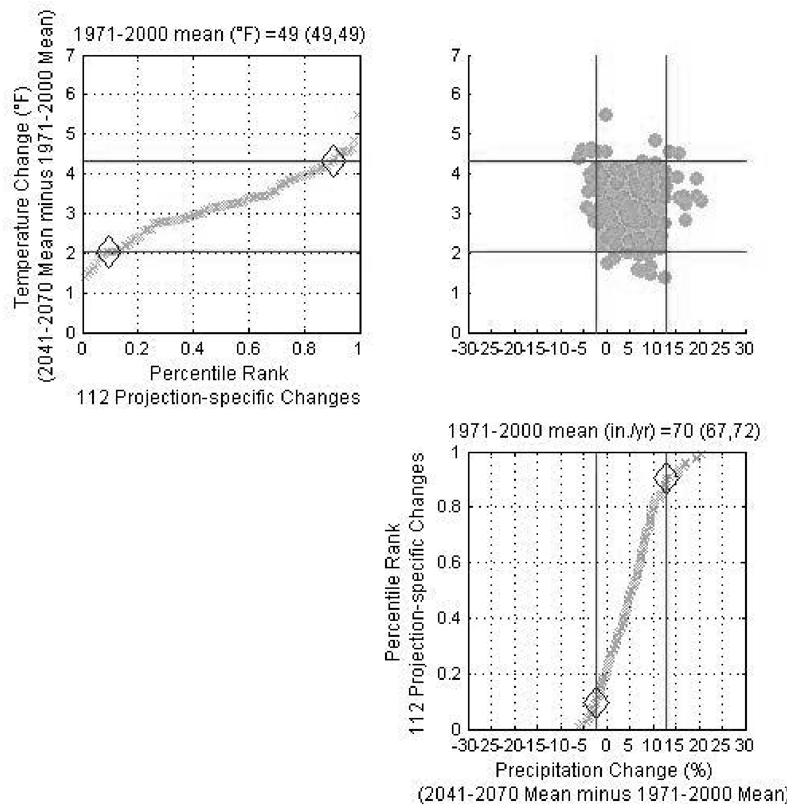

Period-Change Paradigm:
Trinity Reservoir Inflow
Historical and with Climate Change
Historical
Historical reduced 10%
Annual, 1000 Acre-Feet
WaterYear
10% reduction is hypothetical, e.g. based on period-changes in 30-year mean precipitation and temperature (e.g., 1971-2000 to 2031-2060, from a given projection) that are then translated into change in runoff using hydrologic analysis
...
Variability of the Two Inflow Series represents two climates
Annual, 1000 Acre-Feet
Historical
Future

17-01174_011934;17-01174_011934;17-01174_011935;17-01174_011936;17-01174_011937;17-01174_011938;1...

**Time-Developing** view (…and use of Climate Projection Ensembles)

**Period-Change** view, applied to ensemble, resulting in Climate Change Distributions

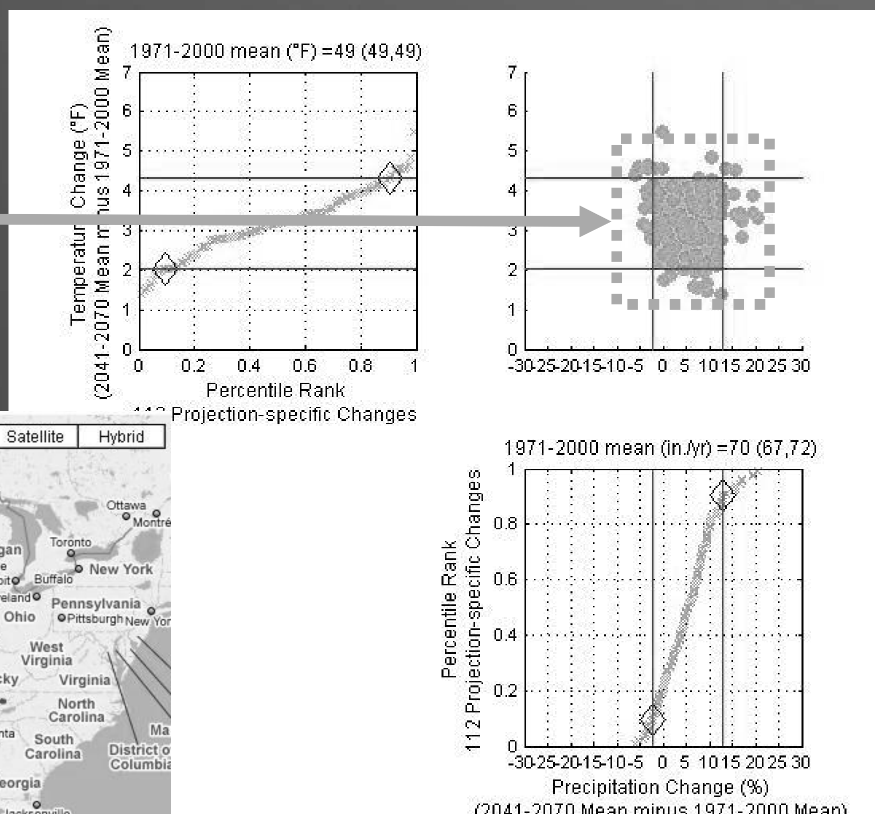


17-01174_011934;17-01174_011934;17-01174_011935;17-01174_011936;17-01174_011937;17-01174_011938;1...

# **Period-Change Application:** (1) metrics: mean T and P, (2) bracket spread, (3) relate to impacts

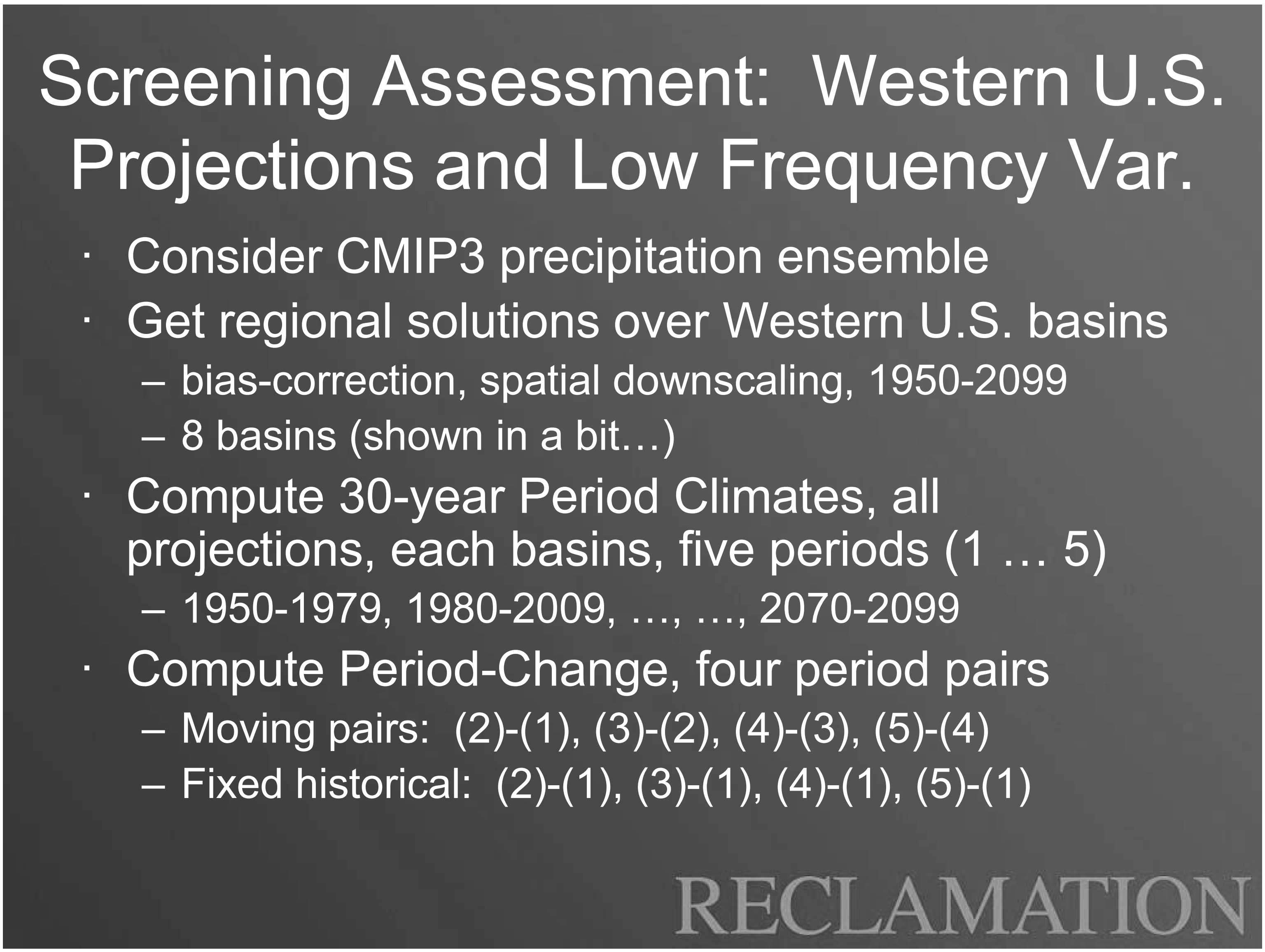
Question: To what extent are these possibilities "*climate change*" versus sampling of "*some climate change and some multi-decadal variability*"?



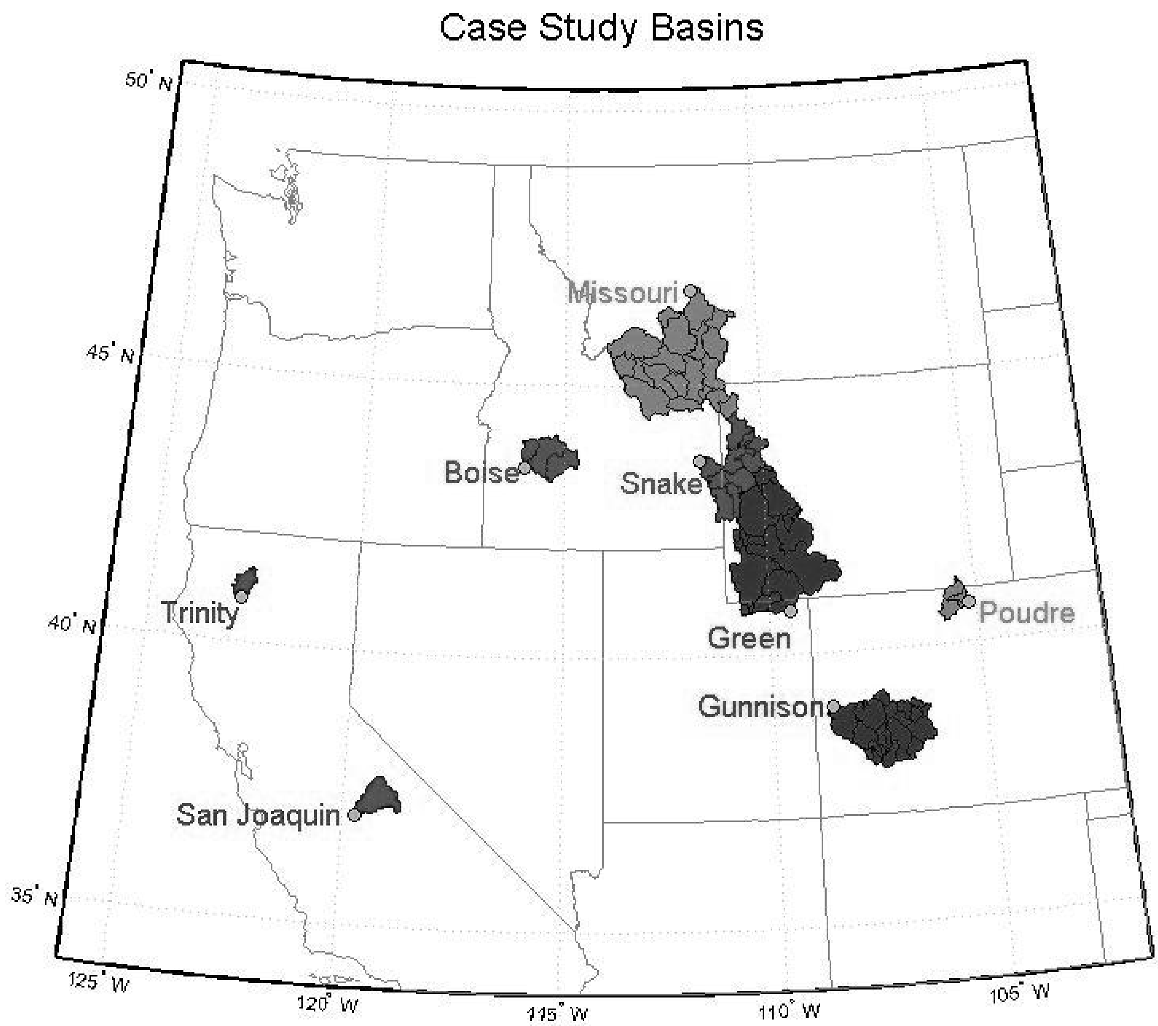

**Vancouver**


Data from: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/

RECLAMATION


Screening Assessment: Western U.S. Projections and Low Frequency Var.
· Consider CMIP3 precipitation ensemble
· Get regional solutions over Western U.S. basins
– bias-correction, spatial downscaling, 1950-2099
– 8 basins (shown in a bit…)
· Compute 30-year Period Climates, all projections, each basins, five periods (1 … 5)
– 1950-1979, 1980-2009, …, …, 2070-2099
· Compute Period-Change, four period pairs
– Moving pairs: (2)-(1), (3)-(2), (4)-(3), (5)-(4)
– Fixed historical: (2)-(1), (3)-(1), (4)-(1), (5)-(1)
RECLAMATION

17-01174_011934;17-01174_011934;17-01174_011935;17-01174_011936;17-01174_011937;17-01174_011938;1...



# Screening Assessment (cont.)

- Examine for low frequency variations – is the sign of change through time?
- Define Case 1
  - moving pairs, does sign change?
    - e.g., (2)-(1) is neg, but (3)-(2) is pos…
- Define Case 2
  - fixed historical, does sign change?
    - e.g., (2)-(1) is neg, but (3)-(1) is pos…

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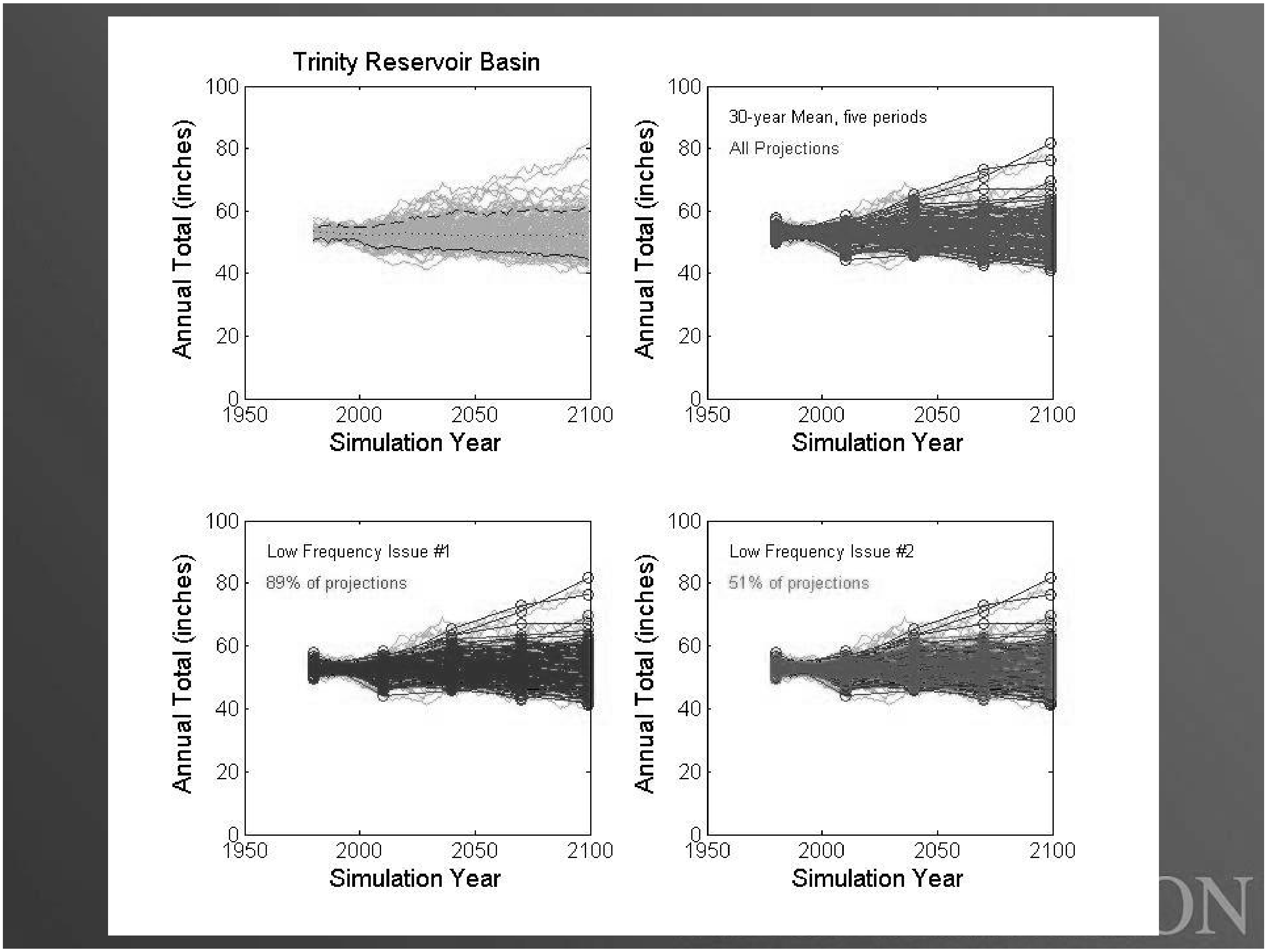
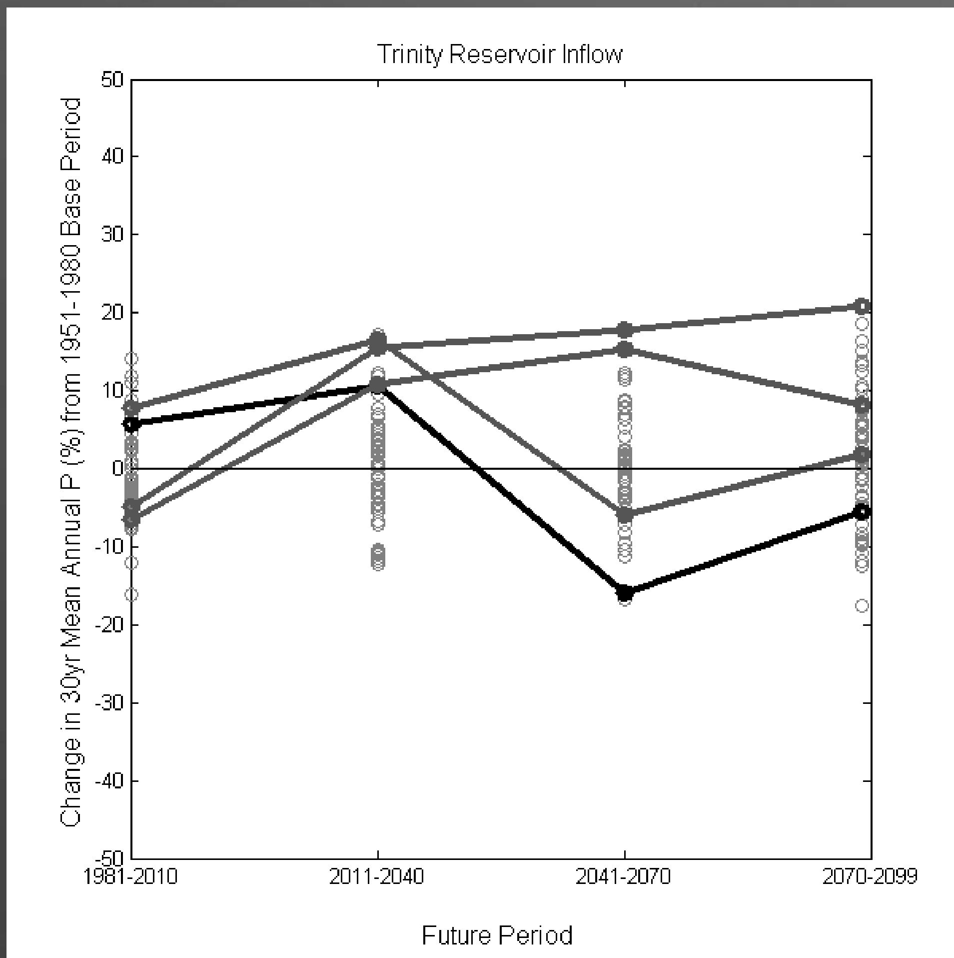

Trinity Reservoir Basin
Annual Total (inches)
Simulation Year
30-year Mean, five periods
All Projections
Low Frequency Issue #1
89% of projections
Low Frequency Issue #2
51% of projections

Trinity:

four example projections showing Case 2 (i.e. period-change sign flip relative to fixed 1950-1979 reference period)




RECLAMATION

# Other basins, Precipitation…

| Basin | Moving Pairs case… % showing sign chng. | Fixed Historical… % showing sign chng. |
|---|---|---|
| Boise (ID) | 80% | 50% |
| Green (WY) | 87% | 52% |
| Gunnison (CO) | 88% | 58% |
| Missouri (MT) | 85% | 52% |
| Poudre (CO) | 79% | 42% |
| San Joaquin (CA) | 91% | 49% |
| Snake (WY) | 78% | 47% |
| Trinity (CA) | 89% | 51% |

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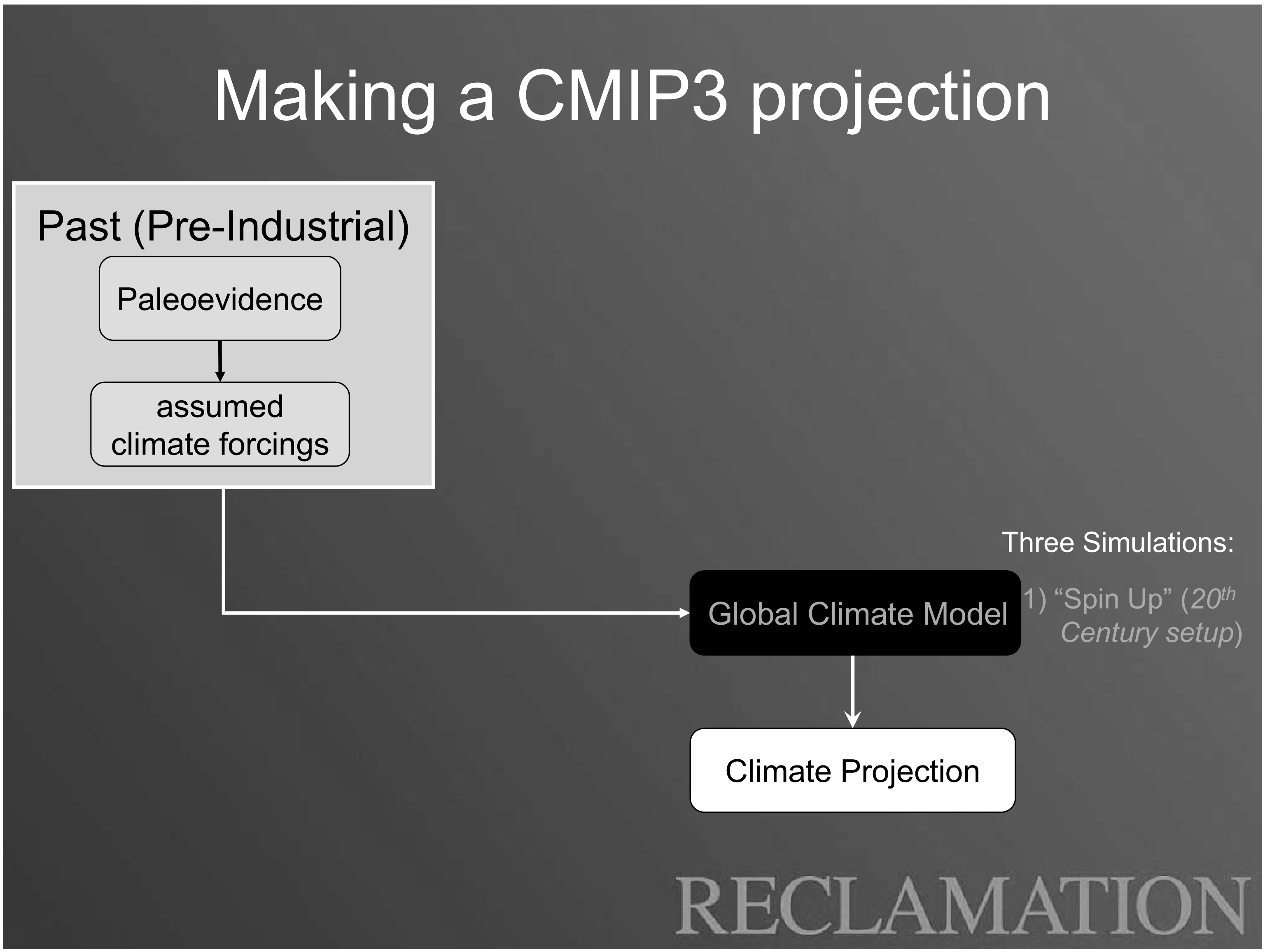

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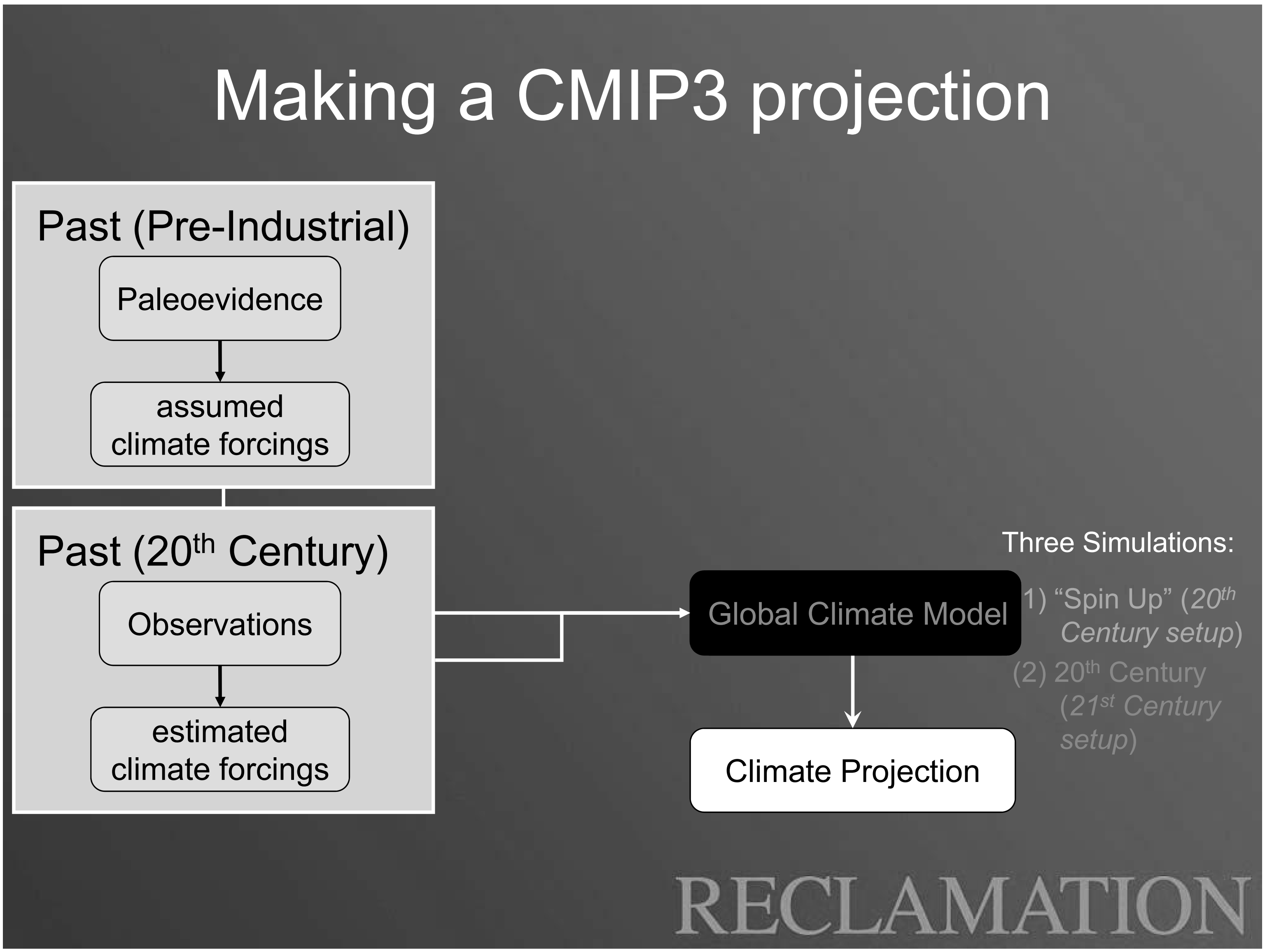

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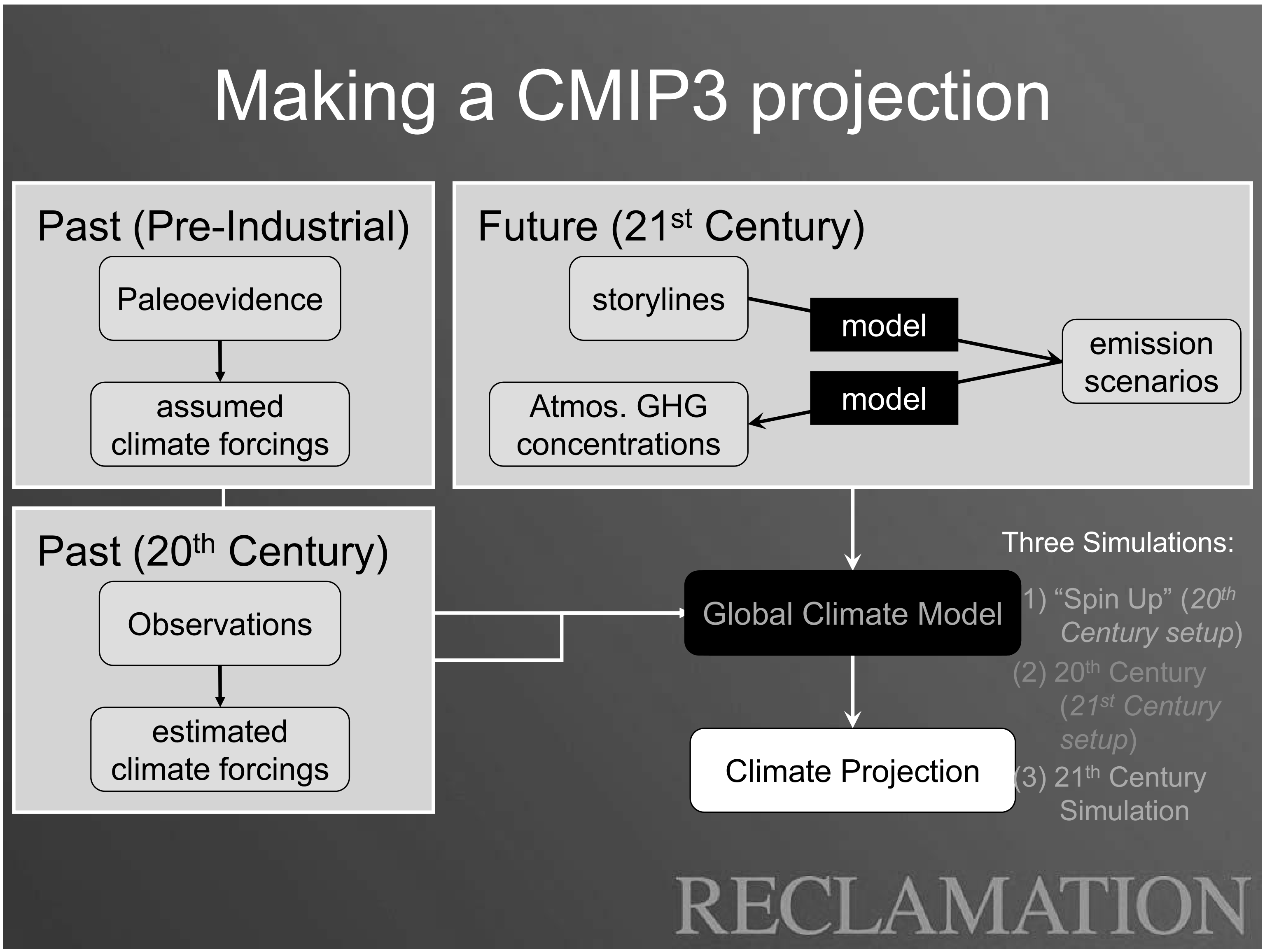

# Issues affecting Regional Period-Change in Global CMIP3 Projections

- CMIP3 projections have different initial conditions
  - Previous slide…
- GCMs express different internal variability
  - Some express no little frequency variability, others a lot
- These two conditions interact, cast time-shadow on interpreting regional projection uncertainty
  - Can last decades, see Hawkins and Sutton (2009)

RECLAMATION

# For Period-Change studies, what are some hanging questions?

- Interpreting the "precipitation climate changes" we sample from projections
  - We discussed low-frequency variability an unstable sign of change through time
  - We didn't discuss the "drifters"…
- How can we be certain we're not double counting variability and mischaracterizing adaptation need?
- Is the Time-Evolving view a remedy?
  - No diagnosis of period-change…
  - …but you need to trust the projected variability…

RECLAMATION

# Questions?

Levi Brekke
Reclamation, Technical Service Center,
Water Resources Planning and Operations Support Group
lbrekke@usbr.gov

RECLAMATION

# Selecting global climate models for regional climate change studies

David W. Pierce[a,1], Tim P. Barnett[a], Benjamin D. Santer[b], and Peter J. Gleckler[b]

[a]Division of Climate, Atmospheric Sciences, and Physical Oceanography, Scripps Institution of Oceanography, La Jolla, CA 92093; and [b]Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, CA 94550

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**Regional or local climate change modeling studies currently require starting with a global climate model, then downscaling to the region of interest. How should global models be chosen for such studies, and what effect do such choices have? This question is addressed in the context of a regional climate detection and attribution (D&A) study of January-February-March (JFM) temperature over the western U.S. Models are often selected for a regional D&A analysis based on the quality of the simulated regional climate. Accordingly, 42 performance metrics based on seasonal temperature and precipitation, the El Nino/Southern Oscillation (ENSO), and the Pacific Decadal Oscillation are constructed and applied to 21 global models. However, no strong relationship is found between the score of the models on the metrics and results of the D&A analysis. Instead, the importance of having ensembles of runs with enough realizations to reduce the effects of natural internal climate variability is emphasized. Also, the superiority of the multimodel ensemble average (*MM*) to any 1 individual model, already found in global studies examining the mean climate, is true in this regional study that includes measures of variability as well. Evidence is shown that this superiority is largely caused by the cancellation of offsetting errors in the individual global models. Results with both the *MM* and models picked randomly confirm the original D&A results of anthropogenically forced JFM temperature changes in the western U.S. Future projections of temperature do not depend on model performance until the 2080s, after which the better performing models show warmer temperatures.**

anthropogenic forcing | detection and attribution | regional modeling

Work for the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (AR4) has produced global climate model data from groups around the world. These data have been collected in the CMIP3 dataset (1), which is archived at the Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory (LLNL). The CMIP3 data are increasingly being downscaled and used to address regional and local issues in water management, agriculture, wildfire mitigation, and ecosystem change. A problem such studies face is how to select the global models to use in the regional studies (2–4). What effect does picking different global models have on the regional climate study results? If different global models give different downscaled results, what strategy should be used for selecting the global models? Are there overall strategies that can be used to guide the choice of models? As more researchers begin using climate models for regional applications, these questions become ever more important.

The present paper and accompanying work investigate these questions. Here we address the regional problem, using as a demonstration case a recent detection and attribution (D&A) study of changes in the hydrological cycle of the western United States (B08 hereafter) (5–8). The insights we have obtained should relate not only to B08, but more generally to regional climate change studies that rely on information from multiple models.

A common approach in such studies is simply to average over all models with available data (9). This approach is justified by global scale results, generally examining only the mean climate, that show the "average model" is often the best (10–14). This procedure weights models that do a poor job simulating the region of interest equally with those that do a good job. It is natural to wonder whether there is a better strategy and whether this result holds for model variability as well.

An increasingly popular approach is to generate metrics of model skill, then prequalify models based on their ability to simulate climate in the region or variable of interest (2–5, 15). However, it is worth examining the underlying assumptions of this strategy. Do the models selected in this fashion provide an estimate of climate change over the historical record that is closer to observations than models rejected on this basis?

**Models.** We use global model January-February-March (JFM) minimum near-surface temperature ("tasmin") over the western U.S. as a surrogate for the multivariate analysis of B08. This variable was used directly by B08 in addition to snow water equivalent and runoff, which are more influenced by small-scale topography. We also reuse the internal climate variability (noise) estimates from B08, obtained from 1,600 years of simulation with 2 different models. B08 and its companion works found that these models provided a realistic noise estimate for use in D&A studies. Our focus here is on the climate change "signal," not the internal variability "noise." The reasoning is that a model with an unrealistic noise level can be identified by comparing with the observations. However, for a D&A study, it is not permissible to qualify a model for use based on how well its climate change signal agrees with observed trends. This is because retaining only models whose climate change signal agreed with observations would make it impossible to find that the observed and model-estimated signals disagree, in essence predetermining the study's conclusions.

Data from 21 global models, many with multiple realizations (see supporting information (SI) *Text* and Table S1), forced by 20th century changes in anthropogenic and natural factors were obtained from the LLNL CMIP3 archive (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). We adopt the CMIP3 terminology: near-surface air temperature is "tas," daily minimum tas is "tasmin," surface temperature is "ts," and precipitation is "pr". The atmospheric resolution for the models varies (12). Many models in the archive have less tasmin than ts and pr data; only 13 have more than 1 realization with tasmin. The period

ENVIRONMENTAL SCIENCES

Author contributions: D.W.P., T.P.B., B.D.S., and P.J.G. designed research; D.W.P. and T.P.B. performed research; D.W.P. and T.P.B. analyzed data; and D.W.P., T.P.B., B.D.S., and P.J.G. wrote the paper.

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[1]To whom correspondence should be addressed at: Division of Climate, Atmospheric Sciences, and Physical Oceanography, Scripps Institution of Oceanography, Mail Stop 0224, La Jolla, CA 92093-0224. E-mail: dpierce@ucsd.edu.

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analyzed is 1960–1999, because most models have no more than 40 years of tasmin data in the archive. To facilitate comparison, all model fields and the observations were put onto a common 1°×1° grid over the western U.S. using bicubic interpolation (Fig. S1).

We compare model temperatures and precipitation with a daily observed dataset gridded at 1/8° longitude by latitude resolution across the western U.S. (16). This dataset is based on the National Weather Service co-operative (co-op) network of stations, adjusted for changes in instrumentation, location, or the surrounding environment.

For sea surface temperature, we combined observed data over the period 1945–1982 (17) with National Centers for Environmental Prediction (NCEP) optimally interpolated data over the period 1983–2007 (ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oisst_v2) (18).

**Statistical Methods.** We evaluate the models with a broad spectrum of metrics based on temperature and precipitation, which are key to climate impacts over most of the world. More details of the metrics are given in *SI Text*, with a brief summary here.

All of our metrics are based on the spatial mean squared error (MSE), which can be decomposed as (19, 20):

$$\mathrm{MSE} = (\bar{m} - \bar{o})^2 + s_m^2 + s_o^2 - 2s_m s_o r_{m,o} \qquad \textbf{[1]}$$

where $m(\mathbf{x})$ is the model variable of interest, $o(\mathbf{x})$ are the observations, overbars indicate spatial averages, $r_{m,o}$ is the product moment spatial correlation coefficient between the model and observations, and $s_m$ and $s_o$ are the sample spatial standard deviation of the model and observations, respectively. When comparing variables with different units, we transform the MSE to a (dimensionless) spatial skill score (SS):

$$\mathrm{SS} = 1 - \frac{\mathrm{MSE}(m,\, o)}{\mathrm{MSE}(\bar{o},\, o)}\,. \qquad \textbf{[2]}$$

A model field identical to observations has a skill score of 1, whereas a model that predicts the correct mean in a limited region, but only as a completely featureless, uniform pattern, yields a skill score of 0.

Let $e_m = (\bar{m} - \bar{o})$ be the "mean error," and $e_p = (s_m^2 + s_o^2 - 2s_m s_o \gamma_{m,o})^{1/2}$ be the "pattern error"; then the root mean squared error (RMSE) $= (e_{\mathrm{m}}^2 + e_p^2)^{1/2}$. This quantity lends itself to a geometric interpretation, where the mean and pattern errors can be plotted on orthogonal axes and the RMSE is the distance to the origin (cf. 20). Similarly, SS can be decomposed into the mean error, the pattern correlation (squared) between the model and observations, and the "conditional bias," which describes a model tendency to over- or under-predict excursions (19). These decompositions are used in the next section.

Temporal variability is evaluated by using spatial patterns of temporal behavior. For example, computing the standard deviation at each point yields a spatial pattern of standard deviations; we then compare this with the same field estimated from observations. When ensemble averaging, either for one or across multiple models, we average the variability measures from each realization. We do not first ensemble average the variable, then compute its variability, which would underestimate the true variability.

We use 42 metrics to characterize each model. We begin with 4 seasonal December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON) averages of 2 variables (tas and pr) in 4 aspects: The seasonal mean and the temporal standard deviation of the seasonal data averaged into 1-, 5-, and 10-year blocks. This process gives 32 metrics. We also include the amplitude and phase of the annual harmonic for each variable, adding another 4 metrics.

The El Nino/Southern Oscillation (ENSO) and North Pacific Decadal Oscillation (NPO or PDO) (21) have a strong effect on the climate of our region. For each mode, we construct one metric describing the climate mode's sea surface temperature pattern in the region where it is defined and additional metrics describing the teleconnected effects of the climate mode in western U.S. tas and pr. This process yields another 6 metrics, for a total of 42. A method for dealing with redundant information in the metrics is given in *SI Text*, section 3.

All of the models have trouble simulating the amplitude of the seasonal cycle of precipitation in the western U.S. (Figs. S2–S5), a problem also noted in the previous generation of models (2). The CMIP3 models do not capture the sharp rain shadow of the Olympic and Cascade mountains, instead smearing the peak precipitation values out over a much wider region than observed. This error is likely related to horizontal resolution and is reduced as model resolution increases (22).

Another poorly simulated field is low-frequency temperature variability in spring (MAM). The models more systematically underestimate the strength of the temperature variability as the averaging period increases from 1 to 5 to 10 years. We also find that precipitation tends to have better skill scores than temperature. In this region at least, the common perception that the global models do a better job simulating temperature than precipitation does not seem to be borne out, with the exception of the amplitude of the annual harmonic of precipitation. However, this finding may be influenced by our choice of normalization in forming the skill scores, and uncertainties in observed pr are likely higher than in tas and are not accounted for in the metrics.

In evaluating the model temperature trends, we use most of the formal, fingerprint-based D&A methodology used in B08 and described more fully in ref. 7. However, no downscaling is done because of the resources that would be required to downscale all 21 models. Instead, observations and model fields are interpolated onto a common 1 °×1 ° grid. Also, we reuse the 2 control runs from B08 (the PCM and CCSM3-FV models) to estimate natural internal climate variability, because we are focusing on the climate change signal rather than the natural internal variability noise. These control runs were shown to be in reasonable accord with observations in their amplitude of ENSO and the PDO, the annual and pentadal variability of regional snow cover, and variability in large-scale precipitation minus evaporation as inferred from downscaled runoff (6, 7).

Briefly, a single spatial fingerprint of warming was defined as the leading empirical orthogonal function of the model-averaged-temperature time series over 9 mountainous regions in the western U.S. (Fig. S1). Year by year, the dot product of the regional temperatures from each model (and the observations) and the fingerprint was computed, yielding a time series of dot products. Our evaluation is based on the least-squares best fit linear trend of the dot product time series, which is simply referred to as the "trend" below. This approach differs from a simple regional averaged temperature trend by assigning weights to each region depending on how much it participates in the model-estimated warming signal.

## Results

The models produce temperature trends in the western U.S. ranging from −0.05 to +0.21 °C/decade. The observed trend is +0.10 °C/decade. All 5 models with a negative trend have only 1 realization, whereas none of the 13 models with more than 1 realization has a negative ensemble-averaged trend. Because of the importance of natural variability in a limited domain, it is not uncommon for models with a strongly positive ensemble-averaged trend to have individual realizations with a negative

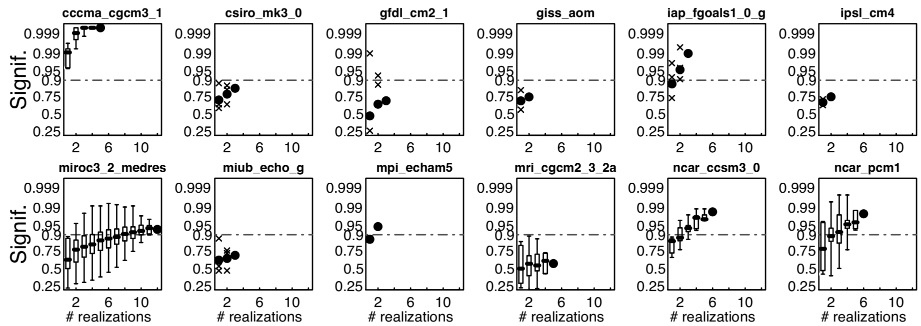


**Fig. 1.** Statistical significance of the model JFM Tmin trend in the western U.S. (projected onto the anthropogenic fingerprint) as a function of the number of ensemble members included in the ensemble averaging. If the number of combinations of ensemble members for the indicated number of ensembles is 4 or more, whisker plots display the minimum value, 25th, 50th, and 75th percentiles, and the maximum value; otherwise, x's indicate the individual values and dots indicate the mean value.

trend. A single model realization does not provide a reliable estimate of the warming signal.

The relationship between $N$ (the number of realizations from a single model included in the ensemble average) and the significance of the model's ensemble-averaged trend is shown in Fig. 1. Significance is assessed by comparing the ensemble-averaged trend with the distribution of trends found in the control runs, which do not include anthropogenic forcing. The significance is computed with all possible combinations of realizations for any given $N$. [For example, if a model has 4 realizations, 3 estimates of significance for $n = 3$ were computed: the average of runs (1, 2, 3), (1, 2, 4), and (2, 3, 4)]. All but 1 model show an upward trend in significance as the number of realizations increases because of the averaging away of natural internal variability. The results from some models suggest their trends would be significant if more realizations were available to reduce the noise (for example, csiro-mk3.0). At least 1 model, mri-cgcm2.3.2a, shows no detectable trend and scant evidence one would be detectable even if more realizations were available.

To explore this result further, we calculate what the D&A results of B08 might have been if the 14 realizations used there had been chosen randomly from all of the models available (63 realizations total), rather than the 10 miroc-3.2 (medres) and 4 ncar-pcm1 realizations actually used. Using 10,000 random selections of 14 realizations, we found 96% of the random trials resulted in a trend significant at the 90% level, and 90% of the trials gave a trend significant at the 95% level. Therefore, the finding of B08 and ref. 8 that the JFM tasmin trend over the western U.S. is both detectable (against the background of natural internal climate variability) and attributable to combined anthropogenic and natural effects is robust to the range of temperature trends found in the CMIP3 models.

**The Role of Model Quality.** Although choosing models randomly verifies the results in B08, it seems we should be able to do better. It is more appealing to use models that do a good job simulating climate in the region of interest. Does doing this make any difference to the results of our D&A study?

We order the models in terms of quality by considering each model's skill scores to be a point in $n_{\mathrm{metrics}}$ dimensional space, where $n_{\mathrm{metrics}} = 42$. In the results shown here, the ordering is given by $\Delta_{SS}$, the Euclidian distance from the model's point to perfect skill at point $(1, 1, 1, \ldots, 1)$. Lower values of $\Delta_{SS}$ indicate better matches to observations. A similar distance-based quality measure has been used before (4), although other workers have determined overall model quality by ranking the models in each metric, then averaging the ranks across the different metrics (12). We emphasize $\Delta_{SS}$ because it allows metrics with a wide spread of skill to have a larger impact on relative model quality than metrics with a small spread. Models can change their position in the ordering by up to 5 places depending on which method is used. However, we also tried the averaged-rank method and found it did not affect our conclusions.

Fig. 2*A* shows how the magnitude of the JFM tasmin trend relates to $\Delta_{SS}$. This value has been calculated using only the 13 models that have more than 1 realization with tasmin, to reduce the effects of natural internal variability. There is no statistically significant relationship between this measure of model quality and the regional tasmin trend. Fig. 2 *B–D* show similar results calculated with the $\Delta$s from the individual skill score components (the pattern correlation squared, conditional bias, and mean error). Again, there are no significant relationships. We repeated the analysis including models with only 1 ensemble member and again found no statistically significant relationships.

These results are with individual models, but perhaps averaging across models is required for any relationships to be discerned. Accordingly, we separated the models into groups of the top 10 and bottom 11 based on $\Delta_{SS}$ and computed the mean JFM tasmin trend for each group. The difference in trend between the groups was compared with Monte Carlo estimates of the difference using

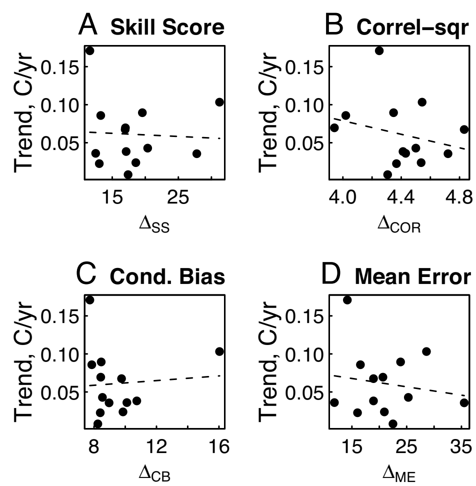


**Fig. 2.** Scatterplots between various measures of model quality (*x* axis) and JFM tasmin trend (C/yr; *y* axis). (*A*) Using $\Delta$ calculated from the skill score (Fig. S2) as the measure of model quality. (*B–D*) Using $\Delta$ from the correlation-squared (Fig. S3), conditional bias (Fig. S4), and unconditional bias (Fig. S5), respectively. (*A–D*) Lower $\Delta$ means better agreement with observations.

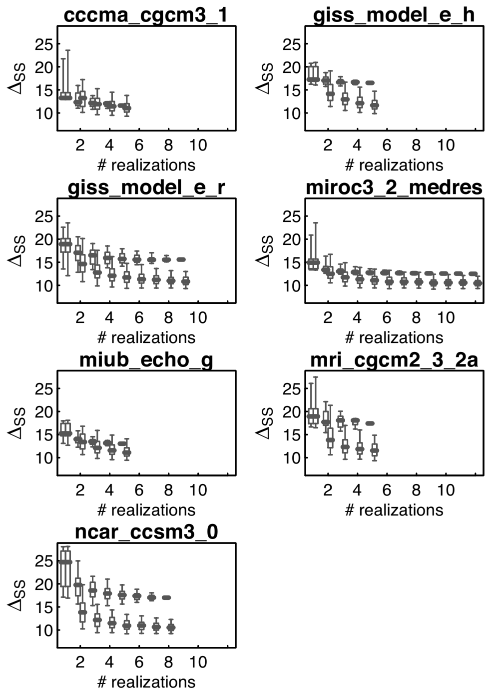


**Fig. 3.** Model distance from perfect skill ($\Delta_{SS}$) as a function of the number of realizations included in the ensemble average. Lower values indicate better agreement with observations. Blue symbols show the change in $\Delta_{SS}$ as progressively more ensemble members from the same model are added. Red symbols show the change as ensemble members from different models are added. Whiskers show 5th, 25th, 50th, 75th, and 95th percentiles. Symbols are horizontally offset by a small amount to avoid overlap.

models partitioned randomly, rather than on the basis of model quality. We found no statistically significant difference in the distribution of trends obtained when partitioning by model quality compared with random partitioning.

In summary, models can be selected for use in regional climate change studies based on the quality of their climate simulation in the region of interest. However, in our demonstration application this selection makes no systematic difference to the D&A results.

**The Multimodel Ensemble.** The multimodel ensemble average (*MM*) is the first, second, first, and third best model in the overall skill score, correlation-squared, conditional bias, and mean error terms, respectively. The superiority of *MM* has been found in previous climate and numerical weather prediction studies (10–14), which have generally examined the mean climate rather than variability. These works attribute the majority of this effect to the averaging removing "random" errors between the models, but typically have shown little evidence supporting this. We now examine whether our results support this mechanism.

Given the important role ensemble size plays in D&A studies (Fig. 1), is *MM* better simply because it includes information from far more realizations than any individual model? Fig. 3 shows $\Delta_{SS}$ as progressively more realizations from the same model (blue) or randomly selected different models (red) are added to the ensemble average. (For both symbols, the case for $n = 1$ includes only realizations from the model indicated in the title; other details are given in *SI Text*.) For most models, skill increases ($\Delta_{SS}$ decreases) more quickly when different models are added to the mix than when more realizations of the same model are included. (The exception is cccma-cgcm3.1, the model with smallest $\Delta_{SS}$.) This holds true even when the number of ensemble members is the same in the same-model vs. multiple-model case. Therefore, the improved performance of *MM* in simulating western U.S. climate does not arise simply because of a larger number of realizations in the multimodel average. Rather, incorporating information from different models contributes to the increase in skill. A similar conclusion was reached when examining global medium-range weather forecasts (19).

Fig. 3 also shows that $\Delta_{SS}$ values tend to approach an asymptote after approximately 5 different models have been averaged together. This behavior suggests that stable results in D&A studies could be reached with far fewer than the 21 models used here.

More insight into how *MM* reduces overall errors is gained by considering the RMSE plots. Fig. 4*A* displays an example for the ENSO pattern in sea surface temperatures. Two features stand out: (*i*) on the mean error ($\bar{m} - \bar{o}$) axis, errors tend to be distributed around 0; and (*ii*) on the pattern error *y* axis, *MM* tends to have less error than any individual model.

For the mean error, these results show that averaging across models increases skill because the errors across different models tend to be offsetting, which supports the line of argument in ref. 11.

The situation is less clear for the pattern error because *MM* tends to fall below (have less error than) the other model results, rather than falling in the center of the model cloud of points. We can write the pattern error as $e_p = s_o(1 + \gamma^2 - 2\,\gamma r_{m,o})^{1/2}$, where $\gamma \equiv s_m/s_o$ (cf. 20). For any particular metric, $s_o$ (the standard deviation of the observations) is fixed, so $e_p$ depends only on $\gamma$ (the ratio of model to observed standard deviation) and $r_{m,o}$ (the pattern correlation). The model values in $\gamma$ - $r$ space are shown in Fig. 4*B*. *MM* falls in the middle of the distribution of individual model points on the $\gamma$ axis; i.e., the errors in the ratio of model standard deviation to observed standard deviation tend to be distributed around 1, similar to the distribution of the mean error around zero. Along the $r$ axis, *MM* is again better than any individual model. Because this now is simply the pattern corre-

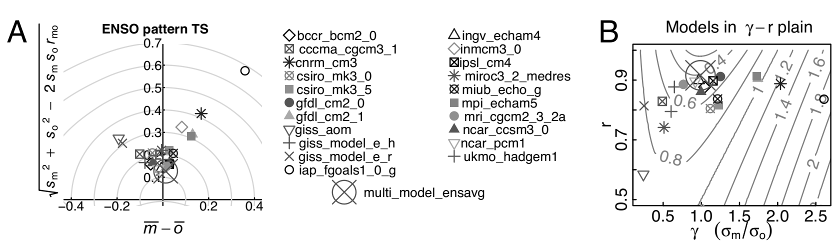


**Fig. 4.** Errors in the individual models and the multimodel ensemble average for one particular metric. (*A*) Shown is RMSE plot for the ENSO pattern in surface temperature (ts). (*B*) Shown is pattern error in ENSO ts (*y* axis of *A*) decomposed into $\gamma$ (the ratio of the standard deviation of the model to the observed) and *r* (the pattern correlation between the model and observed fields). Contours of the *y* axis value (the pattern error) from *A* are also shown on *B*; there is a minimum value of 0 located at (1, 1), and all values increase away from this minimum.

lation between the model and observed fields, we suggest this behavior is caused by effectively random spatial errors in the model patterns, which again tend to average to 0. Examination of various fields, such as the ENSO pattern of surface temperatures, bears this out.

In summary, the *MM* tends to perform better than any individual model, but not because of the greater number of realizations in *MM*. Rather, it can be understood by decomposing the model errors into components arising from the mean error, an error in the ratio of the model's variance to observed, and the pattern correlation between the model and observed. Mean errors tend to be distributed around 0, and the variance ratio tends to be distributed around 1. Averaging across models reduces the error in both these aspects, both in the mean climate and when variability is considered. For the pattern correlation, averaging across models tends to give better correlation with observations than any individual model, which is consistent with the argument that effectively random spatial errors are being reduced by averaging. An analysis of cloud data concluded that the spatial smoothing effect of multimodel averaging also had some beneficial effect, although less than the averaging away of model errors (14).

The *MM* is formed with all models weighted equally. As an experiment, we repeatedly used a minimization procedure (with perturbed initial guesses) to find different sets of model weights that resulted in improved *MM* skill. Although we found many sets of weights with better skill, even when using cross-validation approaches to minimize "curve fitting," individual model weights were not consistent between different sets of weights. We conclude that optimizing *MM* skill in this way is not robust.

Is *MM* always the best choice, even for small subsets of metrics? Using randomly selected subsets of 2 to 41 metrics, we find that *MM* is most likely to be the best choice for 3 or more metrics (Fig. S6). For 8 or more metrics, *MM* has >45% chance of being the best choice, far exceeding the likelihood of any individual model.

Our results show the best way we currently have to use information from multiple global model runs in a regional detection and attribution study is simply to form the *MM*. Neither selecting the models based on the quality of their climate simulations in the region of interest nor forming an optimized ensemble average based on maximizing skill resulted in a superior result over the historical period. Accordingly, we repeated our demonstration test case of JFM tasmin D&A by using *MM* instead of just the 2 global models used in B08. We find both detection and attribution of an anthropogenic climate change signal in western U.S. temperatures are achieved and statistically significant at the 99% level, even with only 40 years of data used here (vs. 50 years in B08).

**Future Projections Based On Model Quality.** We have focused on the historical period because D&A studies require observations. A related question is whether future climate projections in our region of interest are a function of model quality. It has been found that precipitation projections over the western U.S. have no relationship to model quality, but that models with less error over the historical period predict warmer future temperatures than models with more error (2). Examination of a more limited domain, California alone, has found little relationship between the mean or spread of temperature projections and model quality metrics (3, 4).

We computed the multimodel mean annual tas over the western U.S. for all of the models, as well as for the 10 best (least $\Delta_{SS}$) and 11 worst (greatest $\Delta_{SS}$) models using our 42 metrics and the Special Report on Emissions Scenarios (SRES) A1B emissions scenario. The best and worst model means are statistically indistinguishable before the 2080s, but after that the better models predict $\approx$1 °C more warming (2.5 °C for the worst models vs. 3.5 °C for the best models).

A Monte Carlo test shows that ordering the models by quality also has the effect of ordering them by climate sensitivity more than would be expected by chance ($P < 0.05$), with the better models having higher climate sensitivity. Correlations between model quality and climate sensitivity are between 0.53 and 0.58 ($P < 0.05$), depending on which model quality (distance- or rank-based) and climate sensitivity (transient or equilibrium) measures are used.

## Discussion

The availability of global climate model data generated for the IPCC AR4 report has led to an increasing number of studies that downscale global model results to examine regional impacts. This work has examined how to pick the global models to be used in a regional climate change D&A study by using as a test case JFM Tmin warming over the western U.S. (5).

It may be appealing to select global models based on the quality of their simulation in the region of interest. However, our results show this does not result in systematically different conclusions than obtained by picking models randomly. This finding suggests there is little relationship between (*i*) the quality of the model-simulated physics that determines regional temperature and precipitation, and (*ii*) the quality of the physics that determines the anthropogenic climate change signal. The lack of a direct connection between the physics might not be surprising, but the lack of connection between the model quality of the two is disconcerting.

What guidance, then, can be given for selecting which global model runs to use for a regional climate study? First, enough realizations must be chosen to account for the (strong) effects of the models' natural internal climate variability. In our test case, 14 realizations were found to be sufficient in the sense that randomly selected sets of 14 realizations from the pool of all realizations available was quite likely to have given the same results as originally obtained.

Second, we consistently found the *MM* to be superior to any individual model, even on estimates of variability, and for as few as 3 metrics. Although *MM*'s superiority has been found in previous studies focusing on the mean climate, the reasons for this have not generally been elucidated. We have shown this is not simply caused by the larger number of realizations included in *MM*. Rather, it is caused by a tendency for the models to be distributed about a mean error of 0 and a mean ratio of model standard deviation to observed standard deviation of 1. We also find a tendency for the pattern correlation between *MM* and the observations to be higher than for most individual models. Averaging across models therefore tends to reduce all these errors. In our test case, model skill tended to asymptote after including approximately 5 different models, which suggests that stable hindcasts (and forecasts) can be obtained by including a manageably small group of models.

Our test case showed D&A results significant at the 99% level using *MM*. This result is as strong as found in the original work (5), yet using only 40 years of data instead of 50. Using an error-minimization procedure to weight the models that go into making *MM* can enhance overall skill, but is not robust. Also, the future climate projections of the top 10 models show $\approx$1 °C more warming over the western U.S. during this century than the bottom 11 models, although the differences are not distinguishable until after 2080. This result agrees with results using an earlier generation of models (2), although analysis over a smaller domain found that model quality had little effect on the models' projections (3, 4).

Finally, a D&A study involves comparing the climate change signal with the estimate of natural internal variability noise. This work has not assessed the impact of a poor noise estimate on the

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results. Instead we have focused on the signal, reusing an existing noise estimate that was shown to be realistic (5). Choosing a realistic noise estimate is relatively straightforward because it can be done by directly comparing the model results with observations. In contrast, a model's signal cannot be verified against the observations before using that model in a D&A study because that would be circular reasoning. There is no doubt, though, that a poor noise estimate can give misleading D&A results, and selection of a proper noise estimate is an integral part of any D&A study.

**Supporting Information.** Further information, including Figs. S7 and S8, is available in SI.

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# Guidelines for Constructing Climate Scenarios

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Scientists and others from academia, government, and the private sector increasingly are using climate model outputs in research and decision support. For the most recent assessment report of the Intergovernmental Panel on Climate Change, 18 global modeling centers contributed outputs from hundreds of simulations, coordinated through the Coupled Model Intercomparison Project Phase 3 (CMIP3), to the archive at the Program for Climate Model Diagnostics and Intercomparison (PCMDI; http://pcmdi3.llnl.gov) [*Meehl et al.,* 2007]. Many users of climate model outputs prefer downscaled data—i.e., data at higher spatial resolution—to direct global climate model (GCM) outputs; downscaling can be statistical [e.g., *Maurer et al.,* 2007] or dynamical [e.g., *Mearns et al.,* 2009]. More than 800 users have obtained downscaled CMIP3 results from one such Web site alone (see http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/, described by *Maurer et al.* [2007]).

A common request from those applying any of these outputs—whether to conduct impact research or to support adaptation planning—is guidance on how to select, treat, and combine the vast amount of climate model output into useful climate scenarios. A scenario is a postulated sequence of events, whether of human development, climate, etc. Specifically, two questions are often asked: (1) How best can scientists understand and characterize uncertainty? (2) What are some key considerations when selecting and combining climate model outputs to generate scenarios? Addressing these questions in the context of recent research leads to some possible guidelines for creating and applying climate scenarios [see also *Knutti et al.,* 2010]. At this juncture, with a new generation of global and regional climate projections becoming available, such guidelines may prove useful to researchers and policy makers.

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By P. Mote, L. Brekke, P. B. Duffy, and E. Maurer

### *Understanding and Characterizing Uncertainty*

Descriptions of future climate change should include both a central estimate and some representation of uncertainty. Major contributors to uncertainty are imperfect knowledge of (1) the drivers of change, chiefly the sources and sinks of anthropogenic greenhouse gases and aerosols; (2) the response of the climate system to those drivers; and (3) how unforced variability may mask the forced response to drivers.

Quantifying uncertainty in greenhouse gas emissions and other forcings—the drivers of change—remains problematic, and although some studies have attempted to assign probabilities, many instead simply choose among the three forcing scenarios that were widely used for CMIP3. Between now and about 2050 this source of uncertainty is less important than others, because concentration scenarios diverge substantially only after that and because changes before then include a substantially delayed response to previous emissions.

The response of the climate system, the second major contributor to uncertainty, is sometimes characterized by its "climate sensitivity," defined as the change in globally averaged temperature in response to a specified radiative forcing. While this provides a simple characterization based on a single parameter, a full description of response uncertainty would also involve uncertainties in the time-evolving response, and in responses at subglobal scales and of variables other than temperature, which may be proportional to the climate sensitivity, whether on global or regional scales.

Climate sensitivity can be estimated from observations [e.g., *Hegerl et al.,* 2007], but these estimates are subject to uncertainties in both forcing and response. It is hard to rule out very high rates of warming: Most studies estimate that there is at least a 5% chance that the sensitivity exceeds 7°–9°C, for a doubling of atmospheric carbon dioxide ($CO_2$). Some of these studies account for uncertainties in aerosol forcing. Model estimates of climate sensitivity, on the other hand, range only from 2.1°C to 4.4°C

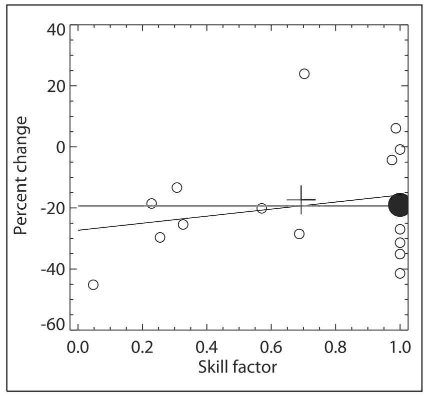


*Fig. 1. Projected change (in percent) in summer precipitation for the 2080s in the U.S. Pacific Northwest from a variety of climate models (open circles, as used by* Mote and Salathé *[2010]), for scenario A2 of the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios. The* x *axis shows the bias factor of* Giorgi and Mearns *[2002]; models with simulated 1970–2000 precipitation close to the observed precipitation, within the range of natural variability, are given a skill factor of 1. Linear fit to the data is indicated (sloping line). There is little difference among changes calculated with all models unweighted (horizontal line), with only the "best" models (models with skill factor >0.9, solid circle), or with weighting the models by their skill factor (plus sign).*

[*Randall et al.,* 2007]. No climate model in the CMIP3 archive represents a low-likelihood, high-sensitivity future climate.

The third important source of uncertainty—how unforced variability masks effects by known drivers of climate change—involves the fact that historical climate simulations do not, and are not intended to, reproduce the exact monthly values of climate variables. A goal of developing scenarios is to distinguish the slowly varying central tendency of change forced externally (by greenhouse gases, volcanoes, etc.) from the unforced variations, which can be important, even dominant, when trying to diagnose and interpret climate change on small time and space scales in the context of global simulations [*Hawkins and Sutton,* 2010]. Using climate projections for impact assessments depends on being able to separate forced responses from natural climate variability [e.g., *Giorgi,* 2005], which

is often accomplished by analyzing the mean and range in an ensemble of simulations differing only in initial conditions.

One thing to note on the uncertainty in climate projections is that on the regional to local scale, where effects are felt, studies may include extremes like cold or heat, storms, and droughts, and detection and attribution of such changes to specific causes (e.g., rising greenhouse gases) becomes more difficult. Consequently, estimating uncertainty in future changes in these local quantities has little theoretical basis.

Further, it must be emphasized that the range of available model results does not, and is not intended to, represent the true physical uncertainty of the quantity in question, although many studies implicitly assume that it does. The range of model results measures consensus, which is important but distinct from uncertainty. Some work on parameter-space exploration has explicitly attempted to quantify the physical aspects of uncertainty [see, e.g., *Stainforth et al.,* 2005].

As a final comment on sources of uncertainty in climate projection information, it is important to understand that the relevance of these sources to a given decision depends on the climate variable and scale of interest (in both space and time). Consideration of which climate aspects are most relevant to a given planning or decision-making process (variables and scales) will help steer attention toward associated aspects of climate projection information, which can lead to a more tailored and relevant discussion of these uncertainties.

*Selecting and Combining Models*

To distill the large number of model simulations into a small group of scenarios, it seems logical to focus on simulations that seem more credible, culling or weighting the results on the basis of some measure of skill. Weighting models may be justified when, for instance, there is a strong correlation between a physical process and a performance metric [*Knutti et al.,* 2010]. Furthermore, while many efforts have focused on ranking climate models based on how they simulate the time-averaged regional climate during a historical period [e.g., *Gleckler et al.,* 2008; *Brekke et al.,* 2008], for impact assessments, in particular, a better basis for model ranking might be their ability to simulate regional climate sensitivity to a change in global climate forcing, provided that a theoretical and observational basis for such analysis can be established.

While methods have varied, it is common to use historical model performance to weight or to choose the "best" models when constructing an ensemble. Some studies have been framed on the premise that ranking leads to better results, though it has been shown that model ranking depends on which skill metrics are considered [*Gleckler et al.,* 2008; *Brekke et al.,* 2008]. In any case, while some studies have shown that ranking models has led to a separation in future responses [e.g., *Walsh et al.,* 2008], others have shown that considering metrics of model skill has generally made little difference either to detection and attribution studies or for representing likely future change. For example, for future average temperature over the western United States, any 14 randomly selected GCMs produced results indistinguishable from those produced by a combination of the "best" models, and the ensemble skill approached the same asymptote once any 6 GCMs were included [*Pierce et al.,* 2009]. Further, using a metric of precipitation trend, 11 randomly selected GCMs produced results almost identical to those using the 11 "best" GCMs [*Knutti et al.,* 2010], and detection and attribution of changes in atmospheric water vapor were insensitive to whether the "best" or "worst" 10 GCMs were used [*Santer et al.,* 2009]. Additionally, little reduction was found in estimating regional precipitation and temperature change uncertainty over northern California [*Brekke et al.,* 2008] or the Pacific Northwest [*Mote and Salathé,* 2010] when based on different sets of "better" climate models, as illustrated in Figure 1. On the basis of these findings and focusing on CMIP3 results, it is unclear whether model culling leads robustly to a separation of future responses and is thus warranted in planning efforts. However, this topic will need to be revisited with CMIP Phase 5 when new GCM simulations will be available to establish performance metrics that may be more robust [*Knutti et al.,* 2010].

Whether or not models are culled, scenario development requires decisions on what to sample from the available ensemble. Some may focus on changes in mean climate, in which case it may be advisable to define such change based on a multimodel average rather than on any single model. However, such definitions still need to be blended with assumptions about climate variability, which may be taken from past observations. Alternatively, the ensemble of opportunity—that is, all the available model runs (as distinct from runs designed to form a meaningfully representative ensemble)—may also be used to estimate changes in both mean and variability. Further work is needed to quantify the credibility of CMIP3 and the new CMIP5 output on various space and time scales, beyond assessing relative skill and culling models, as discussed above. For estimating the central tendency or selecting a single "best" model, then, a suitable approach may be simply to take an unweighted average or median result based on as many models as possible.

In summary, and based on the evaluations cited above, it seems justifiable to forgo culling or weighting climate projections based on perceptions of credibility. This leaves a rather large ensemble of opportunity that may be sampled for climate scenario information. Such sampling may involve identifying individual climate projections that express changes that generally represent the spread of projection information, or choosing a scheme that combines projection information (e.g., ensemble median projected condition through time, or ensemble mean change in period statistics). When several simulations from the same model are available, important questions to ask involve whether differences between outputs of the same model are as large as differences between outputs of different models for various starting parameters. The answer depends on the space and time scales considered, but several studies suggest the answer is that time-averaged differences between outputs of the same model are negligible, especially for longer time horizons [e.g., *Pierce et al.,* 2009]. This implies that the formation of a large ensemble of model simulations [e.g., *Maurer et al.,* 2007] should recognize that two runs from the same model are not likely to be as different as two runs from different models, and therefore one should not simply lump all available simulations together, as this effectively gives more weight to the models contributing more simulations.

*Proposed Guidelines for Model Evaluations*

Results from new evaluations of models including CMIP5 (see http://cmip-pcmdi.llnl.gov/cmip5/) and the North American Regional Climate Change Assessment Program [*Mearns et al.,* 2009] are arriving, along with new downscaled data repositories. Volunteers are also contributing time on their personal computers to create a superensemble of regional climate simulations at 25-kilometer resolution for the western United States (see http://www.weatherathome.net). While these new efforts augment the options of climate scenarios available, they also complicate the development of climate scenarios.

Because modeling efforts both new and old can be difficult to navigate, the following guidelines may help scientists and managers who intend to use climate model scenarios for impact or climate diagnostic research:

1. Understand to which aspects of climate your problem or decision is most sensitive (e.g., which climate variables, which statistical measures of these variables, and at what space and time scales).
2. Determine which climate projection information is most appropriate for the problem or decision (e.g., variables, scales in space and time).
3. Understand the limitations of the method you select.

4. Obtain climate projections based on as many simulations, representing as many models and emissions scenarios, as possible.

5. It may be worth the effort to evaluate the relevant variables against observations, just to be cognizant of model biases, but recognize that most studies have found little or no difference in culling or weighting model outputs.

6. Understand that regional climate projection uncertainty stems from uncertainties about (1) the drivers of change (e.g., greenhouse gases, aerosols), (2) the response of the climate system to those drivers, and (3) the future trajectory of natural variability.

7. Use the ensemble to characterize consensus not only about the projected mean but also about the range and other aspects of variability.

These guidelines make use of several recent research efforts and may provide a better foundation for developing and applying climate scenarios to a range of research and planning questions.

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### Author Information

Philip Mote, Oregon Climate Change Research Institute, Oregon State University, Corvallis; E-mail: pmote@coas.oregonstate.edu; Levi Brekke, U.S. Bureau of Reclamation, Denver, Colo.; Philip B. Duffy, Climate Central, Palo Alto, Calif.; and Ed Maurer, Department of Civil Engineering, University of Santa Clara, Santa Clara, Calif.

# Effects of Hydrologic Model Choice and Calibration on the Portrayal of Climate Change Impacts

PABLO A. MENDOZA

*Department of Civil, Environmental, and Architectural Engineering, and Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, and Research Applications Laboratory, National Center for Atmospheric Research,* Boulder, Colorado*

MARTYN P. CLARK, NAOKI MIZUKAMI, ANDREW J. NEWMAN, MICHAEL BARLAGE, ETHAN D. GUTMANN, AND ROY M. RASMUSSEN

*Research Applications Laboratory, National Center for Atmospheric Research,* Boulder, Colorado*

BALAJI RAJAGOPALAN

*Department of Civil, Environmental, and Architectural Engineering, and Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado*

LEVI D. BREKKE

*Bureau of Reclamation, Denver, Colorado*

JEFFREY R. ARNOLD

*U.S. Army Corps of Engineers, Seattle, Washington*

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ABSTRACT

The assessment of climate change impacts on water resources involves several methodological decisions, including choices of global climate models (GCMs), emission scenarios, downscaling techniques, and hydrologic modeling approaches. Among these, hydrologic model structure selection and parameter calibration are particularly relevant and usually have a strong subjective component. The goal of this research is to improve understanding of the role of these decisions on the assessment of the effects of climate change on hydrologic processes. The study is conducted in three basins located in the Colorado headwaters region, using four different hydrologic model structures [PRMS, VIC, Noah LSM, and Noah LSM with multiparameterization options (Noah-MP)]. To better understand the role of parameter estimation, model performance and projected hydrologic changes (i.e., changes in the hydrology obtained from hydrologic models due to climate change) are compared before and after calibration with the University of Arizona shuffled complex evolution (SCE-UA) algorithm. Hydrologic changes are examined via a climate change scenario where the Community Climate System Model (CCSM) change signal is used to perturb the boundary conditions of the Weather Research and Forecasting (WRF) Model configured at 4-km resolution. Substantial intermodel differences (i.e., discrepancies between hydrologic models) in the portrayal of climate change impacts on water resources are demonstrated. Specifically, intermodel differences are larger than the mean signal from the CCSM–WRF climate scenario examined, even after the calibration process. Importantly, traditional single-objective calibration techniques aimed to reduce errors in runoff simulations do not necessarily improve intermodel agreement (i.e., same outputs from different hydrologic models) in projected changes of some hydrological processes such as evapotranspiration or snowpack.

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*Corresponding author address:* Pablo A. Mendoza, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder, UCB 428, Boulder, CO 80309.
E-mail: pmendoza@colorado.edu

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## 1. Introduction

There is now general agreement in the scientific community that the rising levels of carbon dioxide in the atmosphere are modifying historical climate conditions (Stocker et al. 2014). One of the most relevant impacts of future climate change on society is changes in regional water availability for municipal, industrial, mining, irrigation, hydropower generation, and other activities (Xu 1999; Brekke et al. 2009; Wagener et al. 2010). This situation is particularly critical for the Colorado River basin (CRB) because of the susceptibility of runoff variations due to changes in precipitation and temperature, which stem from changes in evapotranspiration ET processes and snowpack accumulation–melt patterns (Christensen and Lettenmaier 2007). This vulnerability, together with the importance of the CRB for water resources supply for the growing regions of western and southwestern United States, has motivated many climate change studies in this area based on different modeling approaches and therefore resulting in a diverse set of conclusions (Milly et al. 2005; Christensen and Lettenmaier 2007; Hoerling and Eischeid 2007; Ray et al. 2008; Hoerling et al. 2009; Rasmussen et al. 2011, 2014; Miller et al. 2011, 2012; Vano et al. 2012, 2014).

The large uncertainty in estimates of hydrologic changes (i.e., changes in hydrologic variables obtained from hydrologic models) due to climate perturbation is not surprising for the hydrologic research community. In recent decades, many sources of uncertainty for quantifying climate change impacts on water resources have been identified (Chen et al. 2011), including: 1) selection of greenhouse gas emission scenarios, 2) choice of climate model(s), 3) specification of climate model initial conditions, 4) choice of meteorological forcing downscaling methods, 5) selection of hydrological model structures, and 6) choice of hydrological model parameter sets. Understanding risks associated with climate change requires estimating the uncertainty at each step of the modeling process (Xu 1999; Bergström et al. 2001; Wilby 2005; Wilby and Harris 2006; Graham et al. 2007; Chen et al. 2011; Vano et al. 2014). Among these elements, the choices of climate model (Murphy et al. 2004) and downscaling methods (Gutmann et al. 2012, 2014) have received significant attention, because recent studies have found that these are the main contributors to overall uncertainty (Wilby and Harris 2006; Chen et al. 2011).

Although a considerable number of past studies focused on the treatment of uncertainty in climate change projections, only a few have focused on hydrologic model structures and parameter uncertainty. For instance, Wilby (2005) explored parameter stability and identifiability using two hydrologic model structures, finding 1) that transferability of model parameters between wet and dry periods depends on the representativeness of the training period and 2) that model structure uncertainty on projected streamflow can be comparable to the uncertainty due to choice of emission scenario when the simplest model (low-flow period) is considered. Jones et al. (2006) applied three different models in 22 Australian catchments covering a wide range of climates and demonstrated that runoff variations due to changes in rainfall and evapotranspiration are clearly model dependent. Jiang et al. (2007) compared outputs from six hydrological models for mean annual and monthly changes in hydrologic variables due to perturbations of precipitation and temperature, finding 1) that differences across models depend on the climate scenario, the season, and the variable of interest and 2) that models without thresholds in soil moisture have larger differences in projected changes in soil storage. Poulin et al. (2011) used two different hydrological models to compare the effects of model structure against parameter equifinality on the uncertainty of hydrologic simulations, finding that model structure uncertainty dominates. More recently, Miller et al. (2012) found that hydrologic model choice has a large effect on the portrayal of climate change impact in the San Juan River basin. Vano et al. (2012) evaluated hydrologic changes due to perturbed climate scenarios using six hydrologic–land surface models in the CRB, demonstrating large intermodel differences in runoff changes due to shifts in precipitation and temperature. Surfleet et al. (2012) compared a large-scale approach, a basin-scale approach, and a site-specific approach in the Santiam River basin (United States), showing that differences in the portrayal of climate change impacts can be attributed to scale and the ability of the models to capture local hydrological processes.

Despite the increasing awareness of the implications of hydrologic model structures on the estimation of climate change impacts on hydrology, the effects of model representation of specific processes (e.g., evapotranspiration, snow accumulation and ablation, and percolation) on the overall hydrologic model response still remains unclear. In view of this, the main goal of this paper is to compare hydrologic changes obtained with different hydrologic model structures in terms of annual water balance, monthly simulated processes (e.g., ET, snowpack, and soil moisture), and signature measures of hydrologic behavior (e.g., runoff seasonality and long-term base flow) for uncalibrated and calibrated model simulations.

## 2. Study area

The headwaters of the CRB are snow dominated, with approximately 85% of the streamflow resulting from

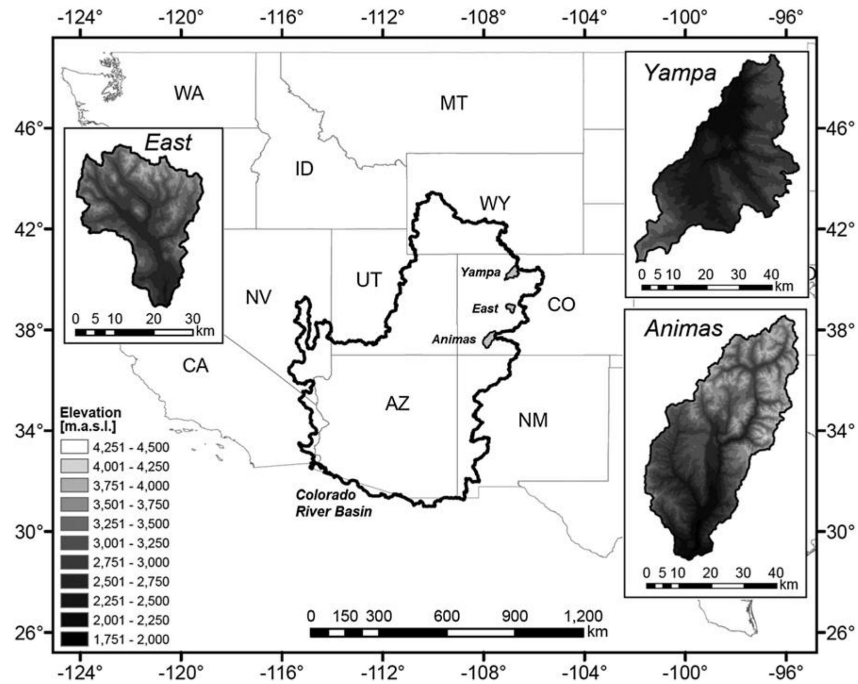


FIG. 1. Location of the basins of interest.

snowmelt. Changes in snowpack can therefore have a large impact on hydrologic processes within the Colorado headwaters (Miller and Piechota 2008). The water resources in the CRB are currently allocated to seven states and Mexico for consumption, irrigation, and hydropower, among other uses. The importance of the CRB for water management and decision making, together with strong evidence of a shift in the hydroclimatology over the past decades (e.g., Miller and Piechota 2008, 2011), has motivated several studies to generate streamflow projections under different future climate scenarios (e.g., Milly et al. 2005; Christensen and Lettenmaier 2007; Hoerling et al. 2009; Bureau of Reclamation 2012). We conduct this study over three basins in the Colorado headwaters region—Yampa River at Steamboat Springs, East River at Almont, and Animas River at Durango—whose location and elevation ranges are shown in Fig. 1. These basins are representative of the main hydroclimatic characteristics of other gauged, unregulated headwater basins throughout the upper Colorado River basin (not shown). Moreover, these catchments have been included in many past climate change studies (e.g., Wilby et al. 1999; Sankarasubramanian and Vogel 2002; Mastin et al. 2011; Milly and Dunne 2011) and, because of their relatively small size compared to the CRB, they offer a unique opportunity to perform extensive analysis involving thousands of model runs (e.g., sensitivity analysis and hydrologic model calibration), to evaluate different approaches in climate change impact assessment, and also to provide detailed understanding of physical processes in the headwaters of the CRB.

Table 1 summarizes the main hydroclimatic characteristics of the three basins for which historical data are available, over an 8-yr period (from October 2000 to September 2008). Mean basin precipitation ranges between 700 and 900 mm yr$^{-1}$, while mean basin elevation is above 2500 m MSL. Among these basins, the Yampa River at Steamboat Springs has the lowest runoff ratio (smallest runoff and largest precipitation amounts), and the East River at Almont has the highest runoff ratio. The land surface of the Yampa and Animas River basins is predominantly covered by deciduous forests (26% at Yampa and 23% at Animas) and evergreen forests (37% at Yampa and 39% at Animas), while the land surface of the East River basin is mainly covered by evergreen forests (29%) and grassland–herbaceous (26%).

## 3. Methods

### a. Meteorological forcings

We use outputs from the regional Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008)

TABLE 1. Characteristics of the three study watersheds. Hydrologic variables correspond to the period from October 2000 to September 2008. Variables $P$, $R$, PE, RE, and DI denote basin-averaged mean annual values of precipitation, runoff, potential evapotranspiration, runoff efficiency, and dryness index, respectively. Values of PE are obtained from PRMS by using a Jensen–Haise formulation (Jensen et al. 1970).

| Location | Area ($km^2$) | Mean basin elevation (m MSL) | Mean annual runoff ($mm\ yr^{-1}$) | Mean precipitation from WRF ($mm\ yr^{-1}$) | Mean annual PE ($mm\ yr^{-1}$) | Mean annual RE ($R/P$) | Mean annual DI (PE/$P$) |
|---|---|---|---|---|---|---|---|
| Yampa at Steamboat Springs | 1468 | 2674 | 228 | 717 | 953 | 0.32 | 1.33 |
| East at Almont | 748 | 3127 | 327 | 782 | 757 | 0.42 | 0.97 |
| Animas at Durango | 1819 | 3098 | 365 | 883 | 885 | 0.41 | 1.00 |

to force our hydrological simulations. The datasets come from the WRF historical runs and pseudo global warming (PGW) simulations with horizontal grid spacing of 4 km described in Rasmussen et al. (2014). The model physics options used in that study included the Noah land surface model, version 3.2 (Noah LSM), with upgraded snow physics (Chen and Dudhia 2001; Barlage et al. 2010); the Thompson mixed-phase cloud microphysics scheme (Thompson et al. 2008); the Yonsei University planetary boundary layer (Hong et al. 2006); and the Community Atmosphere Model's (CAM) longwave and shortwave radiation schemes (Collins et al. 2006). In current climate, the WRF simulations have been validated against SNOTEL sites, and precipitation spatial variability, timing, and intensities are well represented by the model (Ikeda et al. 2010; Prein et al. 2013).

The PGW approach (Schär et al. 1996; Hara et al. 2008; Kawase et al. 2009) consists of adding a mean climate perturbation to the initial and 3-hourly boundary conditions, here taken from the North American Regional Reanalysis (NARR; Mesinger et al. 2006). The climate perturbation used was based on expected changes from the NCAR CCSM3 forced by the A1B scenario. This perturbation is generated by subtracting the current 10-yr (1995–2005) monthly climatology from a future 10-yr (2045–55) monthly climatology. A detailed description of this approach can be found in Rasmussen et al. (2011, 2014).

Meteorological data from WRF simulations are available at hourly time steps and a 4-km resolution for both historical and PGW conditions during the period from October 2000 to September 2008. The variables and temporal disaggregation used depend on specific hydrologic model requirements (Table 2). Figure 2 includes basin-averaged monthly precipitation and temperature from WRF for current and future climate scenarios over the period from October 2002 to September 2008. Note that PGW simulations reflect increases in precipitation during fall and winter and the beginning of spring and a decrease in precipitation during summer over all basins. On the other hand, the increase in temperature tends to be uniform throughout the year in all basins. These signals in precipitation and temperature changes are present at each individual water year (not shown), although monthly precipitation amounts can vary at the basins of interest from year to year.

The single choice of GCM, emission scenario, and the time period over which the climate perturbation was

TABLE 2. Summary of data sources and simulation setup used in this study. For the forcing variables, air temperature at 2 m and wind speed at 10 m are used for hydrologic simulations.

| Model | Vegetation data | Soil data | Forcing variables | Spatial–temporal discretization |
|---|---|---|---|---|
| PRMS | USGS 1-km gridded vegetation type and density data (USDA 1992) | State soil geographic (STATSGO) 1-km gridded soils data (USDA 1994) | Daily precipitation; maximum and minimum daily temperature. | 4 km and $\Delta t = 24$ h |
| VIC | University of Maryland 1-km Global Land Cover Classification (Hansen et al. 2000) | STATSGO 1-km gridded soils data (USDA 1994) | Precipitation, temperature, shortwave and longwave radiation, wind speed, relative humidity, and air pressure. | 4 km and $\Delta t = 1$ h |
| Noah LSM and Noah-MP | National Land Cover Database, 2006 (Fry et al. 2011). | STATSGO 1-km gridded soils data (USDA 1994) | Precipitation, temperature, shortwave and longwave radiation, wind speed, relative humidity, and air pressure. | 4 km and $\Delta t = 1$ h |

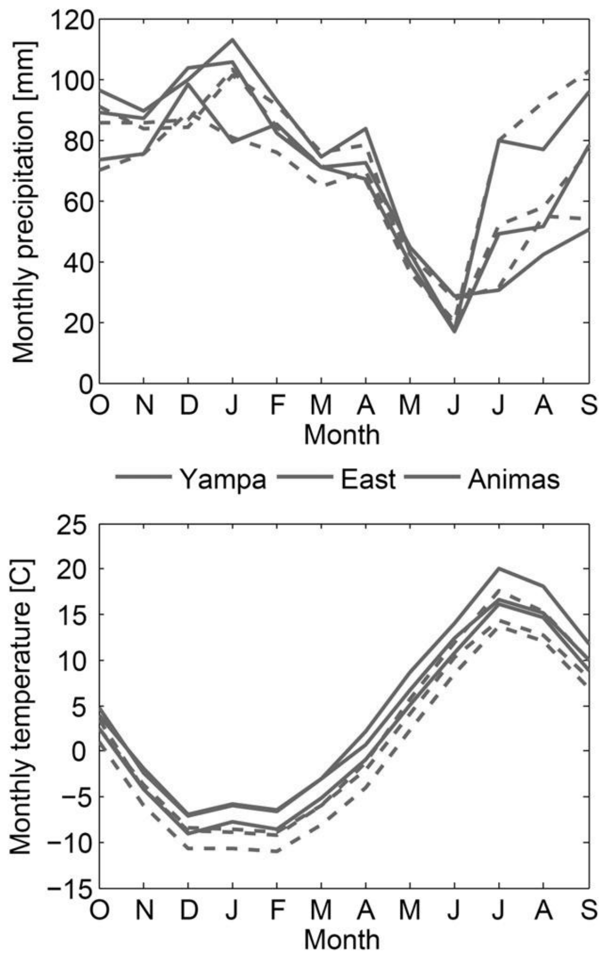


FIG. 2. Basin-averaged monthly (top) precipitation and (bottom) temperature values for CTRL (dashed lines) and PGW (solid lines) WRF outputs used in this study (period from October 2002 to September 2008).

obtained is certainly an important limitation for this study, since they affect the magnitude and direction of climatic shifts. Indeed, Vano et al. (2014) demonstrated the large effects of these decisions on long-term runoff projections over the upper CRB, including results from 19 GCMs and three emission scenarios (A2, A1B, and B1) obtained by Seager et al. (2007) and Christensen and Lettenmaier (2007). However, they also noted that higher future greenhouse gas emissions broadly translate to a warmer and, in most cases, drier climate, implying that a general decrease in runoff should be expected in this region. Although high-resolution climate models limit the number of scenarios that can be analyzed, they offer a more realistic representation of climate features that strongly depend on terrain complexity (Rasmussen et al. 2011, 2014), providing better meteorological fields for the assessment of climate change impacts on hydrology.

### b. *Hydrologic–land surface models*

We choose four hydrologic–land surface models: the U.S. Geological Survey (USGS) Precipitation–Runoff Modeling System (PRMS; Leavesley et al. 1983; Leavesley and Stannard 1995), the Variable Infiltration Capacity model (VIC; Wood et al. 1992; Liang et al. 1994, 1996), the Noah land surface model (Noah LSM; Ek 2003; Mitchell et al. 2004), and the Noah LSM with multiparameterization options (Noah-MP; Niu et al. 2011; Yang et al. 2011). Our choice is based on the fact that the four models cover different degrees of complexity in terms of conceptualization of vegetation, soil, and seasonal snowpack (see Table 3 and Fig. 3 for further details) and also have different parameterizations for some hydrologic processes (different model equations for canopy storage, base flow, etc.). Additionally, these hydrologic model structures have been used in several research studies (e.g., Wilby et al. 1999; Haddeland et al. 2002; Hay et al. 2002; Hay and Clark 2003; Christensen and Lettenmaier 2007; Barlage et al. 2010; Yang et al. 2011; Cai et al. 2014). Our experimental design considers a hydrologic model spatial resolution (4 km) identical to that used in the WRF configuration of Rasmussen et al. (2014), though simulation time steps, forcing variables, and land cover data used for a priori parameter estimates vary depending on specific model requirements (see Table 2 for further details).

In this study, we use a single suite of physics options for Noah-MP, including a Ball–Berry-type model for canopy stomatal resistance, a CLM-type soil moisture factor for controlling stomatal resistance, the simple TOPMODEL-based runoff scheme (SIMTOP) for runoff and groundwater (Niu et al. 2005), a Monin–Obukhov similarity theory–based drag coefficient, supercooled liquid water and frozen soil permeability based on Niu and Yang (2006), a radiation transfer scheme equivalent to a ‘‘mosaic’’ model, a Canadian land surface scheme (CLASS) for snow surface albedo, a partitioning of precipitation into snowfall and rainfall based on Jordan (1991), a Noah-type lower boundary of soil temperature, and a semi-implicit snow–soil temperature time scheme. Readers are referred to Niu et al. (2011) for a full description of each model component.

### c. *Experimental setup*

#### 1) MODEL SIMULATIONS

All model simulations are carried out for the period from 1 October 2000 to 30 September 2008, using the first two years to initialize model states. As done for

TABLE 3. Overview of hydrologic model components used in this study.

| Model | Snow accumulation and melt | Canopy storage | Moisture in the soil column/surface runoff | Base flow |
|---|---|---|---|---|
| PRMS | Two-layer energy–mass balance model. Snowpack energy balance is computed every 12 h. | The precipitation can be intercepted by and evaporated from the plant canopy. The precipitation that is not intercepted by the canopy layer (throughfall) is distributed to the watershed land surface. Interception of precipitation by the plant canopy is computed during a time step as a function of plant cover density and the storage available on the predominant plant cover type in each hydrologic response unit (HRU). | Surface runoff and infiltration are computed using a nonlinear variable-source-area method allowing for cascade flow. | The groundwater zone is conceptualized as a linear reservoir (i.e., base flow is computed as a linear function of groundwater storage). |
| VIC | Two-layer energy–mass balance model. | Water enters one-layer canopy reservoir and can leave as canopy evaporation, transpiration, or throughfall. Canopy throughfall occurs when additional precipitation exceeds the storage capacity of the canopy. Different vegetation classes are allowed within a unique grid cell via a mosaic approach, where energy and water balance terms are computed independently for each coverage class (vegetation and bare soil). | An infiltration capacity function is defined. Vertical movement of moisture through soil follows 1D Richards equation. | Defined as a function of the soil moisture in the third layer (Arno formulation). The function is linear below a soil moisture threshold and becomes nonlinear above that threshold. |
| Noah LSM | One-layer energy–mass balance model that simulates snow accumulation, sublimation, melting and heat exchange at the snow–atmosphere and snow–soil interfaces. | One canopy layer, simple canopy resistance. Simple Jarvis type of canopy resistance function, single linearized energy balance equation representing combined ground–vegetation surface, considering seasonal LAI and green vegetation fraction. | Surface runoff is computed as the difference between throughfall and a maximum infiltration rate. Vertical movement of moisture through soil layers follows 1D Richards equation. | Computed as the product of a scaling factor between 0 and 1 and the hydraulic conductivity of the bottom layer. |
| Noah-MP | Three-layer energy–mass balance model that represents percolation, retention, and refreezing of meltwater within the snowpack. | Snow interception includes loading–unloading, melt–refreeze capabilities, and sublimation of canopy-intercepted snow, along with detailed representation of transmission and attenuation of radiation through the canopy, within- and below-canopy turbulence, and different options to represent the biophysical controls on transpiration. | Surface runoff is an exponential function of depth to water table. Vertical movement of moisture through soil layers follows 1D Richards equation. | Base flow is parameterized as an exponential decaying function of the water-table level (SIMTOP). |

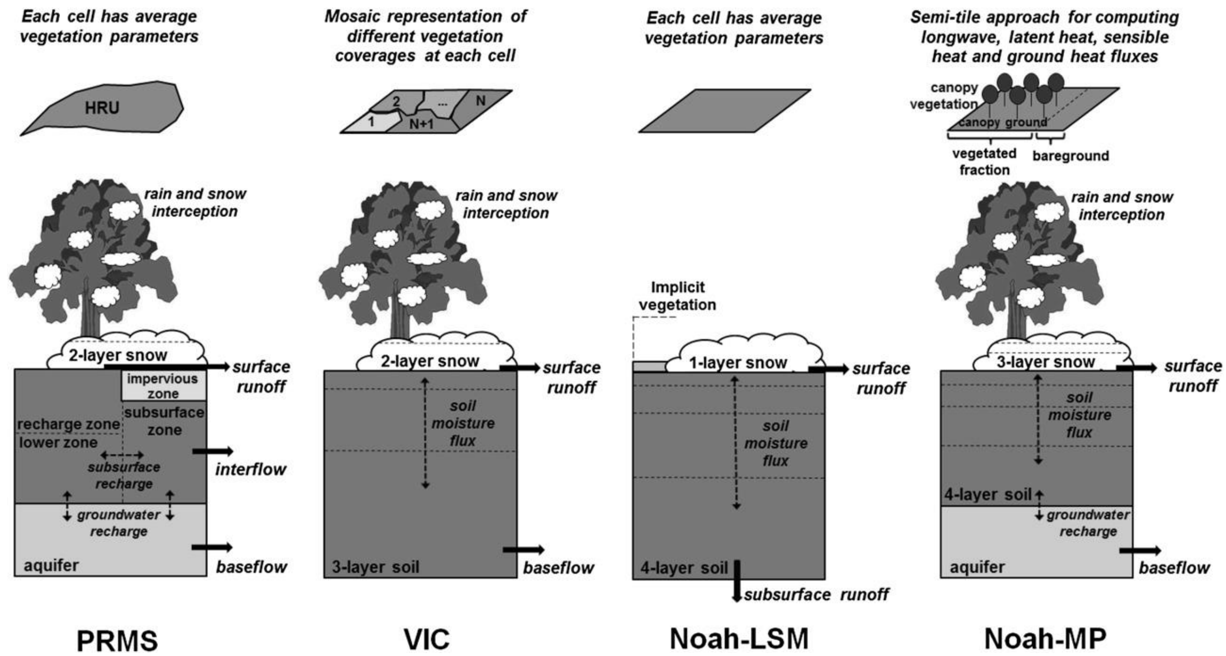


FIG. 3. Comparison of model architectures used in this study: PRMS, VIC, Noah LSM, and Noah-MP.

many past large-scale (i.e., from continental to global scale) hydrologic modeling experiments (e.g., Mitchell et al. 2004; Gerten et al. 2004; Xia et al. 2012), we first compute hydrologic changes using default parameter values obtained from the information sources described in Table 2. Therefore, a comparison of hydrologic change estimates obtained from uncalibrated (i.e., use of default parameters) and calibrated model simulations will provide a comprehensive assessment of the caveats behind traditional methodologies used for climate change impact evaluation.

We calibrate all the models for all basins with the University of Arizona shuffled complex evolution (SCE-UA) algorithm (Duan et al. 1992, 1993) by minimizing the root-mean-square error (RMSE) between observed and simulated daily streamflow for the period between 1 October 2002 and 30 September 2008. Given the short length of WRF reanalysis datasets and that our main priority is to analyze hydrologic change signals, we decided to perform calibration and compute hydrologic changes over the entire period from October 2002 to September 2008 instead of splitting it into calibration and validation datasets. In this study, runoff from hydrologic model simulations is obtained as the sum of surface runoff and base flow, including also interflow if the model is PRMS.

PRMS does not have an explicit river network routing scheme for streamflow; instead, it has a cascade module used to define connections for routing flow from upslope to downslope hydrologic response units and stream segments and among groundwater reservoirs (Markstrom et al. 2008). In VIC, Noah LSM, and Noah-MP, no horizontal routing of surface overland flow, subsurface flow, or channel flow is performed. Instead, basin-averaged runoff is taken as the average of the 1D (vertical) 4-km model grid cells' runoff. During the calibration process, we preserve the spatial variability of a priori model parameters (in case they are spatially distributed) through the adjustment of multiplier values that are applied for each parameter within the entire watershed. We adjust only those parameter multipliers identified as the most sensitive after performing a Distributed Evaluation of Local Sensitivity Analysis (DELSA; Rakovec et al. 2014). The reader is referred to the appendix for a list with the parameters included in the calibration of each model.

Once the calibration process is finished, hydrologic changes are computed for the period from October 2002 to September 2008 by forcing the models with the same meteorological datasets used for uncalibrated simulations.

### 2) EVALUATION METRICS

In this study we evaluate models using six signature measures (Stewart et al. 2005; Yilmaz et al. 2008) to present a comprehensive portrayal of model performance in terms of hydrologic functional behavior. First, we consider the runoff ratio RR as a measure of the

overall water balance and therefore as a signature of the evapotranspiration model component:

$$\mathrm{RR} = R/P, \tag{1}$$

where $R$ is the mean annual runoff and $P$ is the mean annual precipitation.

The second metric selected is the centroid of the daily hydrograph for an average water year, or ‘‘center time’’ of runoff (CTR; Stewart et al. 2005), which is a measure of runoff seasonality:

$$\mathrm{CTR} = \frac{\sum_{i=1}^{N} t_i Q_i}{\sum_{i=1}^{N} Q_i}. \tag{2}$$

In the above equation, $t_i$ is the number of days since 1 October, $Q_i$ is the streamflow associated with $t_i$, and $N$ is the total number of days in a water year.

Three signature measures are extracted from the flow duration curve (FDC). First, the FDC midsegment slope (FMS) represents the variability, or flashiness, of the flow magnitudes:

$$\mathrm{FMS} = \frac{\log(Q_{m_1}) - \log(Q_{m_2})}{m_1 - m_2}, \tag{3}$$

where $m_1 = 0.2$ and $m_2 = 0.7$, and thus, $Q_{m_1}$ and $Q_{m_2}$ are the flows with exceedance probabilities of 0.2 and 0.7, respectively. A steep slope of the FDC indicates flashiness of the streamflow response, whereas a flatter curve indicates a relatively damped response and a higher storage (Yadav et al. 2007; Casper et al. 2012). Second, the FDC high-segment volume (FHV) is a measure of the catchment response to high rainfall/snowmelt events:

$$\mathrm{FHV} = \sum_{h=1}^{H} Q_h, \tag{4}$$

where $h = 1, 2, \ldots, H$ are the flow indices into the array of flows with exceedance probabilities lower than 0.02. Third, the FDC low-segment volume (FLV) is the measure of the long-term base flow:

$$\mathrm{FLV} = \sum_{l=1}^{L} [\log(Q_l) - \log(Q_L)], \tag{5}$$

where $l = 1, 2, \ldots, L$ is the index into the array of flow values located within the low-flow segment (0.7–1.0 exceedance probabilities) of the FDC and $L$ is the index for the minimum flow.

Finally, we choose the FDC median (FMM; Yilmaz et al. 2008) as a measure of midrange flows:

$$\mathrm{FMM} = \mathrm{median}[\log(\mathrm{FDC})], \tag{6}$$

where log(FDC) represents the array of sorted daily streamflow values in log space. The median is selected because it is less sensitive to a skewed distribution than the mean of the streamflow time series.

## 4. Results and discussion

### a. Model performance

Figure 4 summarizes model performance for the period from October 2002 to September 2008 in terms of mean annual streamflow, monthly streamflow, and flow duration curves, for both uncalibrated and calibrated simulations. None of the hydrologic model structures considered in this study is able to reproduce seasonal runoff patterns or flow duration curves using default parameter values (Fig. 4a). Although this is not surprising and has been widely reported in the literature, many studies that seek to characterize the water balance at the continental scale make use of noncalibrated or semicalibrated land surface models (e.g., Mitchell et al. 2004; Xia et al. 2012). Importantly, the inclusion of a ‘‘classic’’ calibration process based on the minimization of the RMSE between simulated and observed total runoff still leaves inconsistencies across different model structures (Fig. 4b). Some models show large errors in mean annual runoff or seasonal runoff patterns even after calibration, and the FDC is not accurately represented by any model, particularly for low flows.

To assess how much model performance improves functional catchment behavior through a traditional single-objective calibration strategy, we analyze the differences between simulated and observed values of signature measures of hydrologic behavior for both uncalibrated and calibrated model simulations (Fig. 5). Parameter adjustment clearly improves the simulation of those signatures whose formulations are closer to the objective function used for calibration (in this case RMSE, which gives more relative importance to high flows). Consequently, calibration results in smaller intermodel differences in the runoff ratio, the response to large precipitation events (i.e., FHV), and midrange flows (i.e., FMM). On the other hand, intermodel differences in the runoff seasonality (i.e., CTR), the flashiness of runoff (i.e., FMS), and baseflow processes (i.e., FLV) are still pronounced after model calibration. Examples of this are Noah-MP and VIC at Yampa when looking at FMS, or Noah LSM at East and PRMS at Animas when evaluating baseflow processes (i.e., FLV),

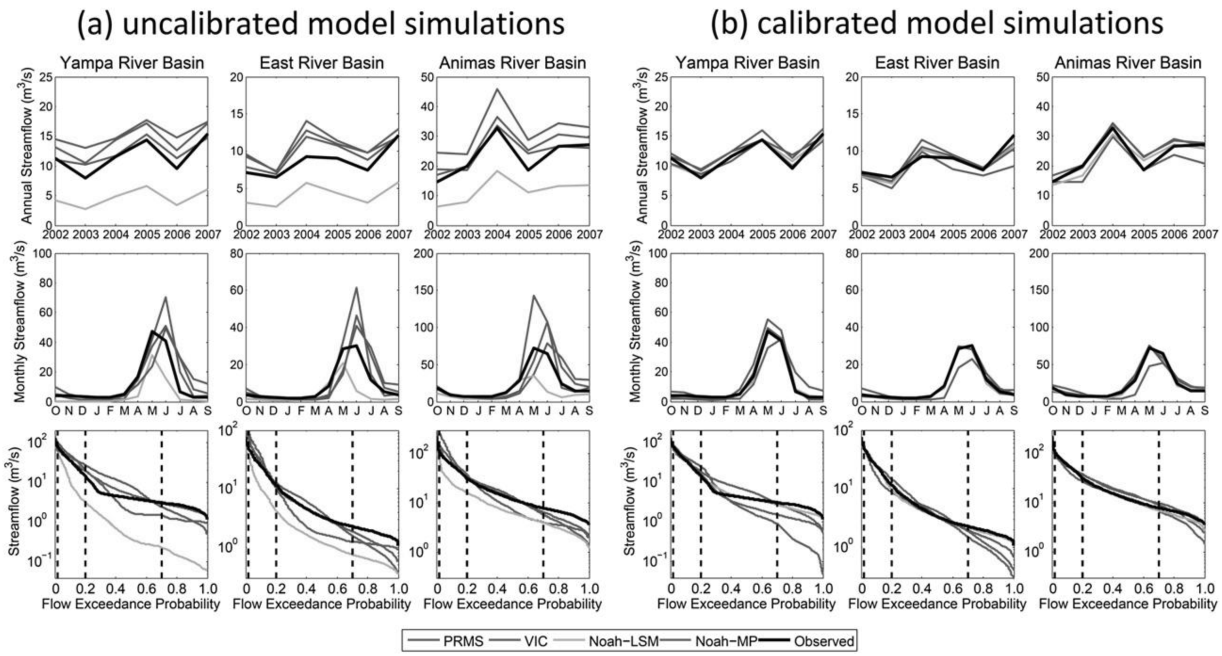


FIG. 4. Historical streamflow (a) uncalibrated and (b) calibrated simulation outputs for the period from October 2002 to September 2008 for all basins: mean annual streamflow for all water years (top), mean monthly flows (middle), and flow duration curves (bottom).

where calibration has actually degraded the signature measures. While a different objective function (e.g., based on the log of the flows) might improve other metrics (e.g., FLV), no single metric is likely to capture all catchment behaviors.

### *b. Changes in annual water balance*

To what extent does parameter calibration decrease the uncertainty in projected changes in the overall water balance? To provide an initial answer to this question, we first analyze both uncalibrated and calibrated hydrologic model outputs in the runoff–ET space for a single climate scenario. In Fig. 6, the diagonal lines represent basin-averaged mean annual precipitation for current and future climate scenarios over a 6-yr average period (from October 2002 to September 2008). The intersection of these lines with the $x$ axis indicates that all precipitation becomes runoff, while the intersection with the $y$ axis indicates that the system converts all precipitation into ET. In the same figure, different symbols represent outputs coming from different hydrologic model structures for current climate (unfilled) and future climate (solid). A symbol located exactly on the diagonal lines represents a simulation with negligible changes in storage over the 6-yr simulation period, whereas symbols located below the 1:1 line denote increases in storage, and those above denote decreases in storage. Intermodel differences in precipitation partitioning are represented by the distance between different symbols (unfilled or solid), while the distance between a particular symbol (e.g., star for Noah-MP) for current (unfilled) and future (solid) climate scenarios represents the hydrologic change signal.

The results obtained from uncalibrated simulations (Fig. 6a) indicate that intermodel differences are much larger than the magnitude of hydrologic change signals. Furthermore, all the models have the same hydrologic change signal direction (increase in ET and decrease or negligible change in mean annual runoff) with the exception of Noah LSM, which projects increases in both runoff and ET (Fig. 7a). As expected, intermodel differences in runoff (Fig. 6b) decrease considerably (i.e., less variability along the $x$ axis) and the direction of hydrologic change signal (Fig. 7b) is more consistent across models (i.e., less runoff and more ET for future climate scenario) after calibration, with the exceptions of VIC at Yampa and PRMS at East. Noah-MP stands out from the rest of the models because the direction and magnitude of the signal is not substantially altered after the calibration (cf. Figs. 7a,b). On the other hand, considerable shifts in projected runoff changes are obtained after calibrating PRMS at East (from $-11$ to $6\,\mathrm{mm\,yr^{-1}}$), VIC at Yampa (from $-7$ to $4\,\mathrm{mm\,yr^{-1}}$), and Noah LSM at all basins (from 8 to $-21\,\mathrm{mm\,yr^{-1}}$ at Yampa, from 6 to $-21\,\mathrm{mm\,yr^{-1}}$ at East, and from 12 to $-13\,\mathrm{mm\,yr^{-1}}$ at Animas). Moreover, an important

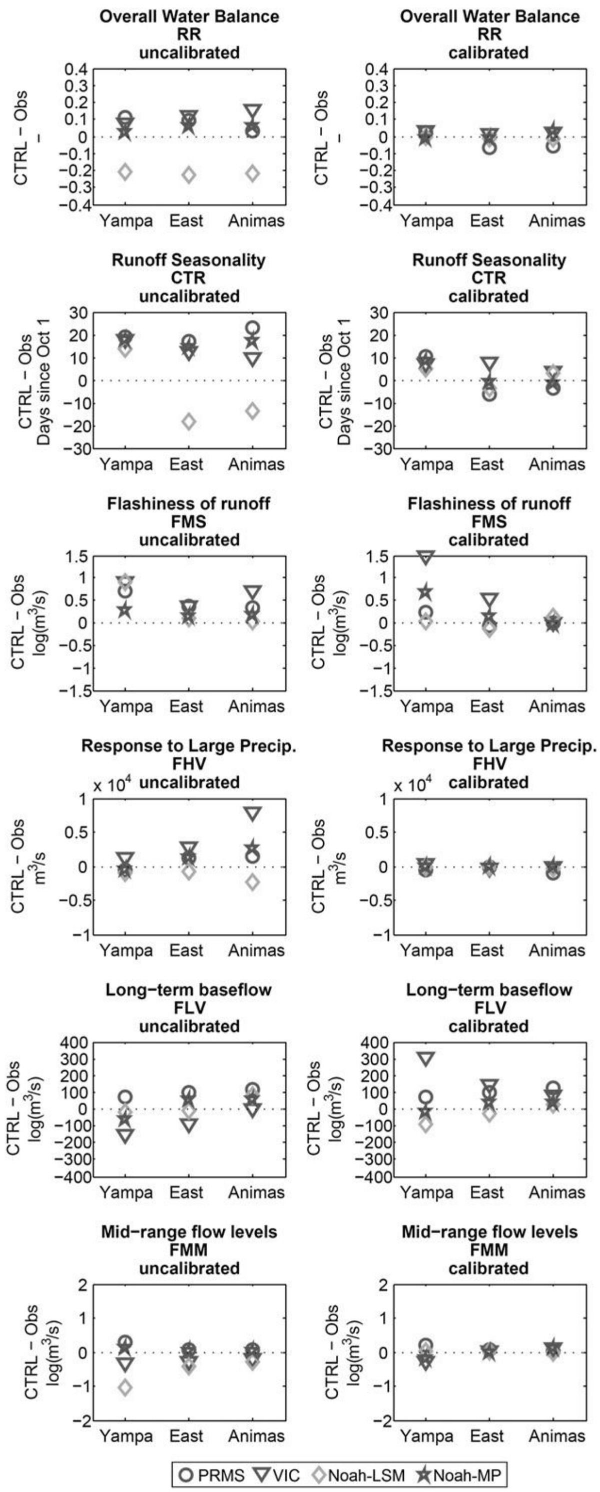


FIG. 5. Difference between simulated (CTRL) and observed (Obs) signature measures of hydrologic behavior (period from October 2002 to September 2008) obtained from (left) uncalibrated and (right) calibrated model runs.

result from Fig. 6b is that intermodel differences in precipitation partitioning into runoff and ET are still comparable or even larger than the magnitude of hydrologic change signal, even after model calibration.

Table 4 summarizes fractional hydrologic changes on an annual basis for both uncalibrated and calibrated model simulations over a 6-yr average period (from October 2002 to September 2008). A suite of different variables is included in order to illustrate how model structure selection and parameter calibration may affect the direction and magnitude of projected changes on hydrologic systems. For instance, in the East River basin, the magnitude of fractional changes in maximum snow water equivalent (SWE) increases with PRMS (from −0.10 to −0.19) and decreases with Noah-MP (from −0.09 to −0.04) after the calibration process. Another example is given by base flow at the Yampa River basin: fractional changes switch from positive to negative values after calibrating PRMS (from 0.03 to −0.04) and Noah LSM (from 0.08 to −0.08), but they shift from negative (−0.04) to positive (0.01) values if the model selected is VIC. Similarly, Table 4 illustrates the effects of calibration on fractional changes in total runoff (e.g., PRMS at East, VIC at Yampa, and Noah LSM at all basins), capturing (although in different units) the results from Fig. 7 that were previously discussed. The key result from Table 4 is that the intermodel differences in the hydrologic impacts of the CCSM–WRF climate scenario vary substantially across models (i.e., the differences in the columns of Table 4 for each basin), and the intermodel differences are larger than the mean multimodel change signal for most metrics.

### c. *Monthly changes*

Figure 8 shows mean monthly runoff values obtained from all models for both uncalibrated and calibrated simulations over a 6-yr average period (from October 2002 to September 2008). As expected, the use of default parameters (Fig. 8a) translates into very different catchment responses under current and future climate scenarios, and these differences are also reflected in projected monthly changes [PGW minus control (CTRL)]. The largest and smallest changes in runoff are obtained from VIC and Noah LSM, respectively, and the seasonality of these shifts differs substantially across models. For instance, the Noah LSM simulates increases in runoff during February–April, extending to May for the Yampa River basin, and a decrease during May–June, while Noah-MP generates an increase in runoff during March–May and a decrease during June–September (Fig. 8a). Much more consistent results across models are obtained when parameter calibration is

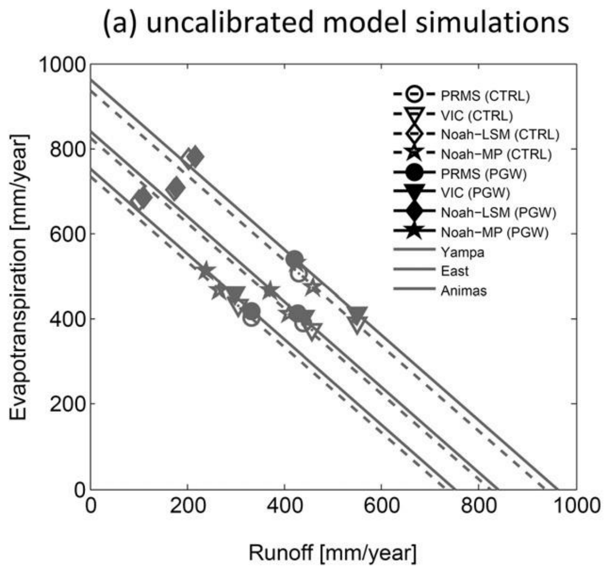


FIG. 6. Partitioning of current (CTRL) and future (PGW) basin-averaged mean annual precipitation (diagonal; mm $yr^{-1}$) into basin-averaged mean annual runoff (*x* axis; mm $yr^{-1}$) and evapotranspiration (*y* axis; mm $yr^{-1}$) across different model structures and basins for the period from October 2002 to September 2008. Results are displayed for (a) uncalibrated and (b) calibrated model simulations.

performed (Fig. 8b), and this is reflected in both the magnitude and seasonality of runoff variations. A key question that follows from here is whether intermodel similarities in runoff changes are due to intermodel agreement in changes of other water storages and fluxes.

With the aim to explore possible reasons for the (mis) match in projected runoff changes among different model structures, we analyze monthly changes in model states and fluxes obtained from both uncalibrated and calibrated runs (Fig. 9). The variables included in this analysis are ET, SWE, soil moisture, base flow, and surface runoff. To improve consistency in the comparison across models, we consider only the top two soil layers for the computation of soil moisture storage with VIC, Noah LSM, and Noah-MP, and the addition of interflow to surface runoff for PRMS. Figure 9a shows large differences in changes for ET, base flow, and surface runoff among models, while more consistent results in terms of seasonal cycles and amplitude are obtained for snowpack (except Noah LSM) and soil moisture. However, intermodel differences of soil moisture and surface runoff are preserved or emphasized after the calibration process (Fig. 9b). Furthermore, one can infer from the results displayed in Figs. 8b and 9b that the same runoff changes might be obtained using different hydrologic models due to very different mechanisms; that is, internal compensations of model structures and model parameter errors are adjusted through

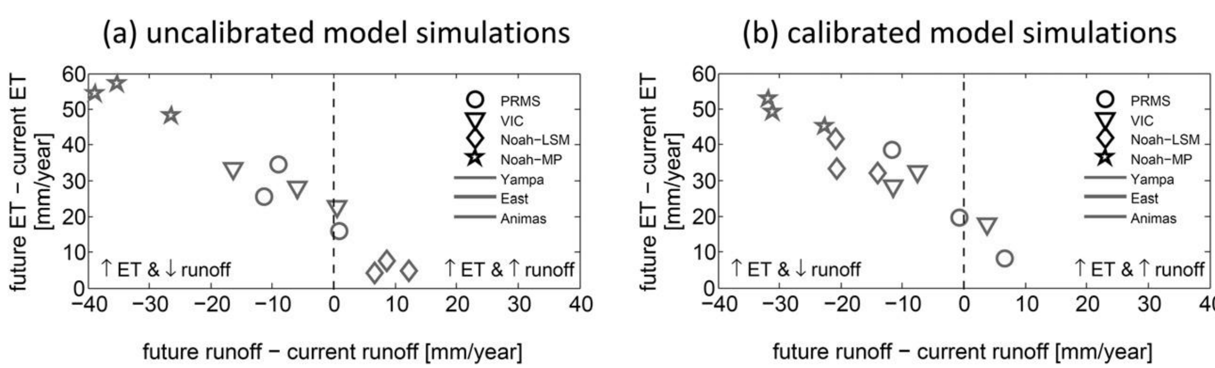


FIG. 7. Projected changes in basin-averaged mean annual runoff (*x* axis; mm $yr^{-1}$) and evapotranspiration (*y* axis; mm $yr^{-1}$) across different model structures and basins for the period from October 2002 to September 2008. Results are displayed for (a) uncalibrated and (b) calibrated model simulations.

TABLE 4. Values of fractional change [(PGW − current climate)/current climate] in basin-averaged total accumulated precipitation, peak SWE, accumulated ET, accumulated surface runoff, accumulated base flow, and accumulated total runoff (sum of surface runoff and base flow, including interflow if using PRMS) averaged for an average water year (from October 2002 to September 2008) obtained from both uncalibrated and calibrated model simulations. Also included are the changes in dates of maximum SWE for each basin/model, where the values represent CTRL minus PGW dates of maximum SWE. Mean values for each basin are given in boldface.

| | Yampa | | | | | East | | | | | Animas | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | PRMS | VIC | Noah LSM | Noah-MP | **Mean** | PRMS | VIC | Noah LSM | Noah-MP | **Mean** | PRMS | VIC | Noah LSM | Noah-MP | **Mean** |
| Total precipitation | 0.02 | 0.02 | 0.02 | 0.02 | — | 0.02 | 0.02 | 0.02 | 0.02 | — | 0.03 | 0.03 | 0.03 | 0.03 | — |
| Maximum SWE | | | | | | | | | | | | | | | |
| Uncalibrated | −0.12 | −0.08 | −0.12 | −0.09 | **−0.10** | −0.10 | −0.10 | −0.14 | −0.09 | **−0.11** | −0.12 | −0.14 | −0.14 | −0.10 | **−0.12** |
| Calibrated | −0.16 | −0.10 | −0.11 | −0.12 | **−0.12** | −0.19 | −0.04 | −0.09 | −0.04 | **−0.09** | −0.22 | −0.06 | −0.08 | −0.06 | **−0.11** |
| Date of maximum SWE | | | | | | | | | | | | | | | |
| Uncalibrated | 25 | 32 | 7 | 13 | **19.25** | 18 | 13 | 3 | 12 | **11.50** | 12 | 31 | 46 | 31 | **30.00** |
| Calibrated | 25 | 2 | 7 | 0 | **8.50** | 25 | 4 | 4 | 6 | **9.75** | 12 | 1 | 5 | 0 | **4.50** |
| Evapotranspiration | | | | | | | | | | | | | | | |
| Uncalibrated | 0.04 | 0.07 | 0.01 | 0.10 | **0.05** | 0.07 | 0.09 | 0.01 | 0.13 | **0.07** | 0.07 | 0.06 | 0.01 | 0.12 | **0.06** |
| Calibrated | 0.04 | 0.04 | 0.08 | 0.11 | **0.07** | 0.02 | 0.06 | 0.07 | 0.10 | **0.06** | 0.07 | 0.06 | 0.06 | 0.09 | **0.07** |
| Base flow | | | | | | | | | | | | | | | |
| Uncalibrated | 0.03 | −0.04 | 0.08 | −0.08 | **0.00** | −0.02 | −0.05 | 0.05 | −0.04 | **−0.02** | −0.03 | 0.00 | 0.07 | −0.04 | **0.00** |
| Calibrated | −0.04 | 0.01 | −0.08 | −0.08 | **−0.05** | 0.01 | −0.03 | −0.04 | −0.05 | **−0.03** | −0.11 | −0.02 | −0.03 | −0.04 | **−0.05** |
| Surface runoff | | | | | | | | | | | | | | | |
| Uncalibrated | −0.01 | 0.01 | 0.14 | −0.12 | **0.01** | −0.03 | 0.00 | −0.01 | −0.15 | **−0.05** | −0.01 | 0.01 | −0.01 | −0.12 | **−0.03** |
| Calibrated | 0.03 | 0.02 | −0.08 | −0.24 | **−0.07** | 0.03 | −0.01 | −0.14 | −0.14 | **−0.07** | 0.01 | 0.00 | −0.06 | −0.09 | **−0.03** |
| Total runoff | | | | | | | | | | | | | | | |
| Uncalibrated | 0.00 | −0.02 | 0.09 | −0.10 | **−0.01** | −0.03 | −0.04 | 0.04 | −0.09 | **−0.03** | −0.02 | 0.00 | 0.06 | −0.08 | **−0.01** |
| Calibrated | 0.00 | 0.01 | −0.08 | −0.13 | **−0.05** | 0.02 | −0.03 | −0.06 | −0.09 | **−0.04** | −0.03 | −0.02 | −0.04 | −0.05 | **−0.03** |

calibration in a way that allows similar responses from different watershed models. The clearest example in this case study is observed in the East River basin, where monthly changes in runoff are very similar (Fig. 8b); nevertheless, VIC compensates very large variations in soil moisture with other variables such as ET and base flow, and PRMS does the same with large variations in ET, SWE, and surface runoff.

### *d. Projected changes in catchment behavior*

Finally, we compare the effects of model choice and parameter adjustment on projected changes in

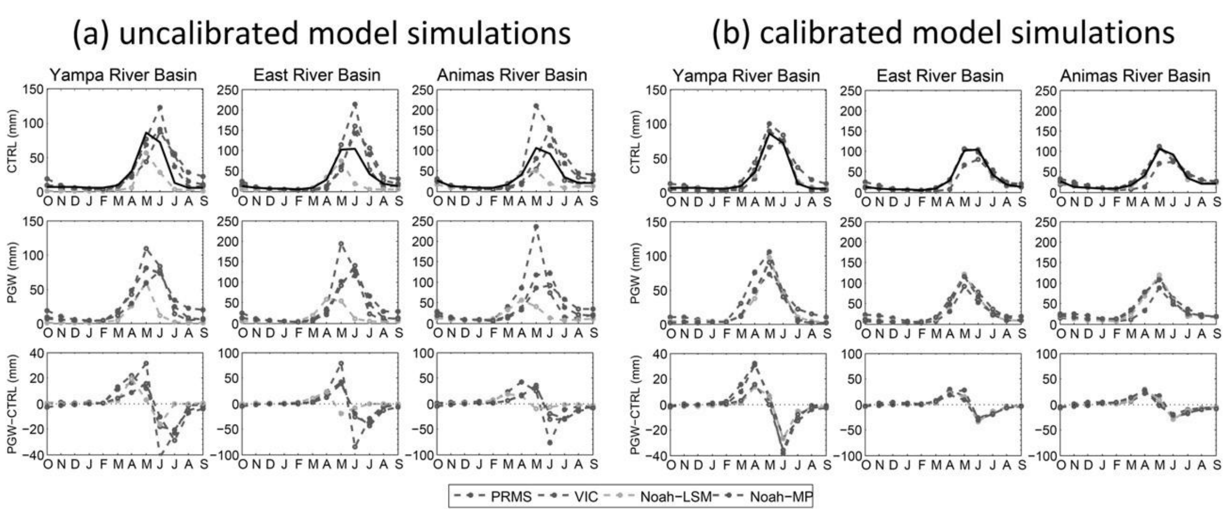


FIG. 8. Current (CTRL), future (PGW), and changes (PGW − CTRL) in basin-averaged monthly runoff for (a) uncalibrated and (b) calibrated model simulations over a 6-yr average (from October 2002 to September 2008). The black lines in CTRL represent historical observations.

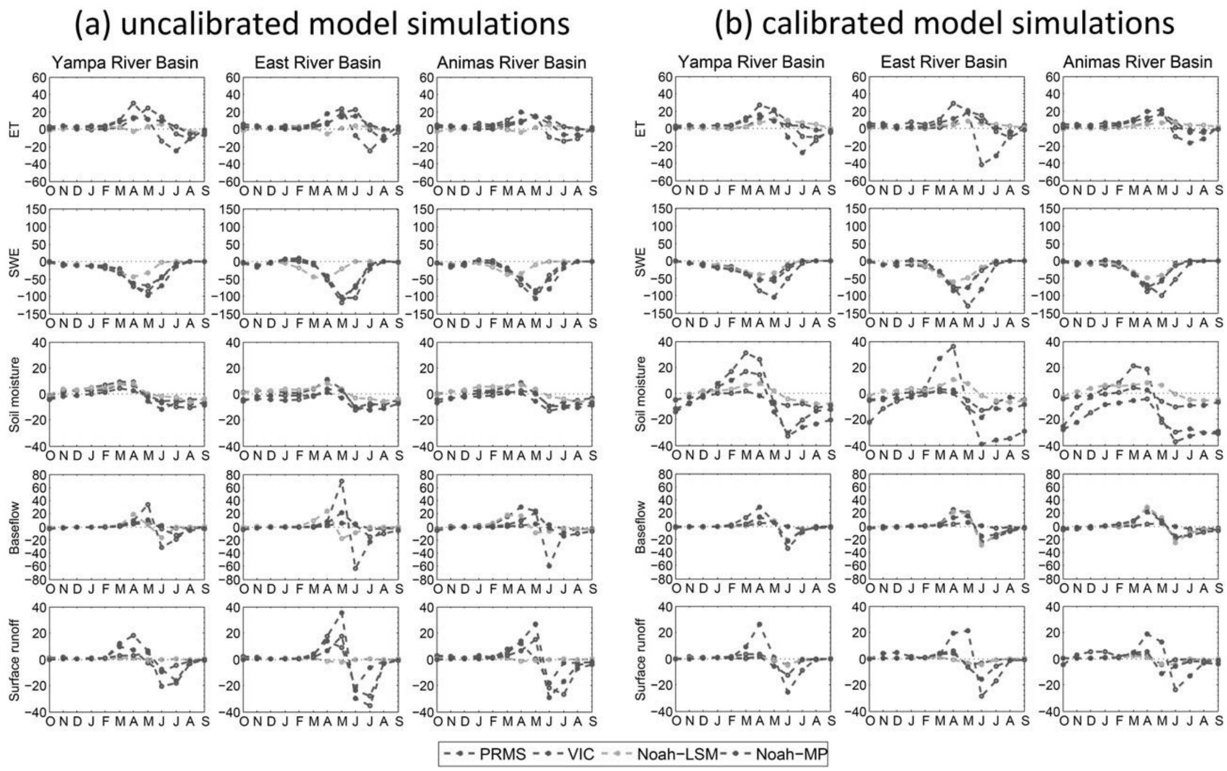


FIG. 9. Monthly changes (PGW − CTRL) in basin-averaged fluxes and states (mm) for (a) uncalibrated and (b) calibrated model simulations over a 6-yr average (from October 2002 to September 2008).

hydrologic signatures. Figure 10 illustrates differences between future (PGW) and current (CTRL) signature measures of hydrologic behavior for all models/basins, computed from both uncalibrated (Fig. 10, left) and calibrated (Fig. 10, right) model runs. The main result from Fig. 10 is that calibration helps to decrease the uncertainty associated with model choice in projected changes of those signatures closely related with the objective function selected. Clear examples of this are the response to large precipitation events (i.e., FHV) and midrange flow levels (i.e., FMM). However, the uncertainty due to model structure increases for some signatures and basins [e.g., runoff seasonality (i.e., CTR) at Yampa and East, flashiness of runoff (i.e., FMS) at Yampa, and baseflow processes (i.e., FLV) at Yampa and Animas]. Moreover, different hydrologic model structures can provide opposite changes (signal) of some signature metrics even after calibration (e.g., FLV and FMS).

It is interesting to see that for both uncalibrated and calibrated model outputs, the only consistent signal obtained with all models is a negative change in runoff seasonality (CTR), which is directly related with an expected decrease in snowpack under the PGW scenario (i.e., shorter accumulation season and earlier melt season). For the case of calibrated model simulations, a general reduction of high-flow volumes (FHV) occurs regardless of the model choice (except PRMS at Yampa). The results in Fig. 10 illustrate the strong interplay between model structure and model parameters and suggest the following hypothesis: different calibration approaches may lead to very different answers from those displayed in Fig. 10 (right) or, put differently, that subjective decisions on configuring and calibrating hydrologic models may have unexpected and underappreciated impacts on the portrayal of climate change impacts. Current work is focused on this problem in order to get a better comprehension of uncertainties introduced by model structure selection and different parameter estimation strategies.

## 5. Conclusions

This study aims to improve our understanding of the effects of hydrologic model choice on the portrayal of climate change impacts. Specifically, we assess the effects of model structure selection on: 1) historical performance in terms of hydrologic signature measures and 2) hydrologic changes due to a climate

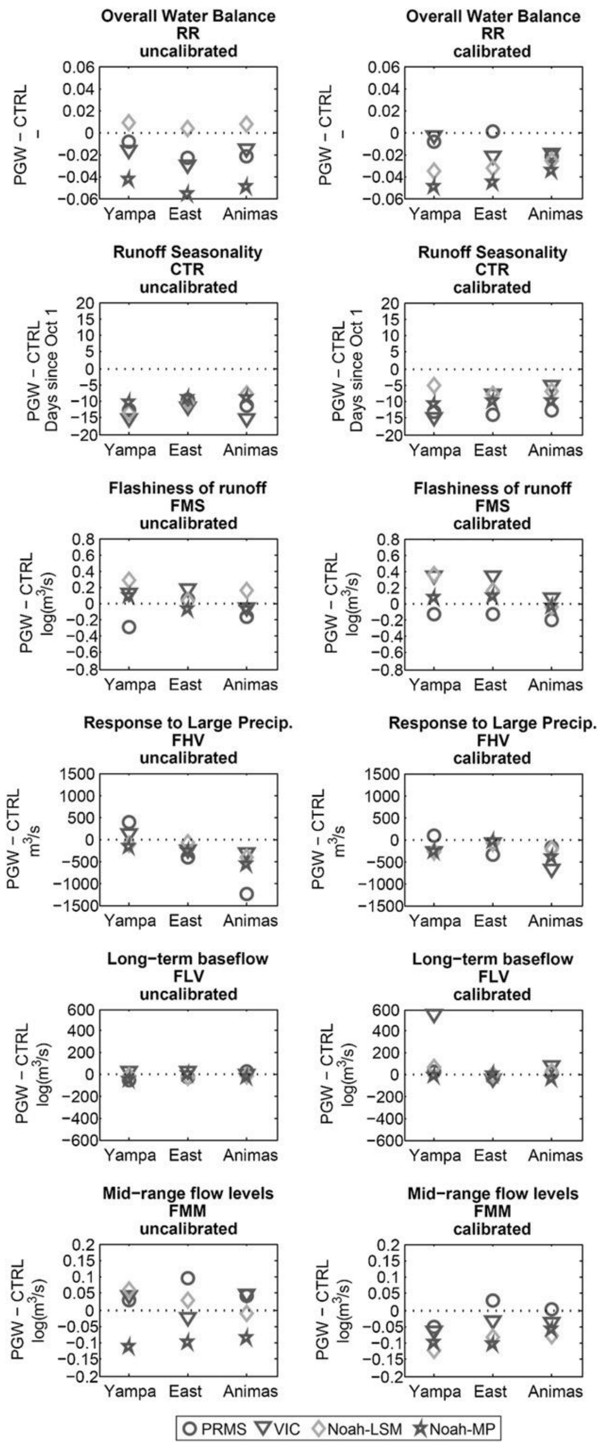


FIG. 10. Impact of climate change on signature measures of hydrologic behavior for both (left) uncalibrated and (right) calibrated model simulations over a 6-yr average (from October 2002 to September 2008).

perturbation, with focus on the overall water balance and catchment processes. Because several efforts aimed to characterize future changes on the hydrology at the continental or global scales have made use of hydrologic–land surface models with little or no calibration, we include in our analysis a comparison between uncalibrated and calibrated model outputs. Our main findings are as follows:

- Intermodel differences in portrayal of climate change impacts are substantial, even after calibration. These differences reflect on projected changes in overall water balance, monthly changes in individual simulated processes, and signature measures of hydrologic behavior.
- In this paper, better values for specific process evaluation metrics (i.e., signature measures) were obtained over the historical period from October 2002 to September 2008 only if their mathematical formulation was close to the RMSE between simulated and observed runoff (i.e., the calibration objective function).
- Consequently, single-objective calibration procedures constrain intermodel differences in climate change impacts for hydrologic metrics that are closely related to the objective function. In this study, calibration improved intermodel agreement on future projected changes of the response to large precipitation events, and midrange flow levels. However, intermodel agreement decreased when evaluating the change of other metrics related with flashiness of runoff and baseflow processes.
- Although traditional calibration methods certainly improve intermodel agreement in projected changes of the overall water balance (i.e., partitioning of precipitation into ET and runoff), intermodel differences in the runoff–ET space are comparable and even larger than the hydrologic change signal for the scenario examined here.
- Single-objective calibration approaches aimed to reduce errors in runoff simulations do not necessarily enhance intermodel agreement in projected changes of some hydrological processes such as ET or snowpack. Moreover, identical changes in runoff might be obtained with different hydrologic model structures for very different reasons, indicating that the calibration process is compensating structural and parameter errors to give us ''good'' runoff simulations, but not to correctly reproduce catchment processes.

The main conclusion from this study is that subjective decisions in the selection of hydrologic model structures and parameters have large effects on the

portrayal of climate change impacts. Moreover, these effects may directly impact adaptation strategies. For instance, 1) the diversity of projected changes in runoff amounts and timing affects reservoir operations such as release schedules and magnitudes (Miller et al. 2012); 2) uncertainty in responses to large precipitation events propagates to flood frequency estimates, which are required for design and safety assessment of infrastructure (Raff et al. 2009); 3) uncertainties in ET projections relate with irrigation demands and should therefore be considered in agricultural adaptation plans; and 4) the diverse responses obtained in terms of long-term base flow may impact future drought risk evaluation (Wilby and Harris 2006) and policies related with minimum instream flow requirements (Vano et al. 2014).

The implication of our findings is that previous studies evaluating the impacts of climate change on water resources may be overconfident. Moving forward, it is necessary to have a much more comprehensive assessment of the myriad of uncertainties in climate risk assessments; in particular, to improve characterization of uncertainties in hydrologic modeling applications.

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## APPENDIX

### Parameters Included in the Calibration Process

The model parameters included in the calibration process are selected based on background sensitivity analysis performed for each hydrologic–land surface model. In this study, we use the DELSA (Rakovec et al. 2014) method to quantify parameter sensitivity, using the RMSE between observed and simulated streamflow as objective function. In DELSA, the assessment of parameter sensitivity is based on local gradients of the model performance index with respect to model parameters at multiple points throughout the parameter space. A number of soil, vegetation, runoff, and snow parameters were considered in DELSA for each model: 17 for PRMS, 34 for VIC, 17 for Noah LSM, and 30 for Noah-MP.

Based on the sensitivity analysis results, the numbers of parameters calibrated are 8 for PRMS, 9 for VIC, 11 for Noah LSM, and 14 for Noah-MP. These parameters are listed in Tables A1–A4.

TABLE A1. Summary of PRMS parameters considered for calibration. If the parameter is distributed, calibration is performed on the basis of multipliers. Although description and units refer to actual parameters, the values in boldface represent the multiplier values (instead of actual parameter values). For parameter jh_coef, the range is provided for a multiplier applied to each monthly value.

| Parameter | Description | Units | Distributed | Calibration range Min | Calibration range Max |
|---|---|---|---|---|---|
| jh_coef | Monthly Jensen–Haise air temperature coefficient | F | No | 0.36 | 2.86 |
| fastcoef_lin | Linear flow routing coefficient for fast interflow | $day^{-1}$ | No | 0 | 10 |
| fastcoef_sq | Nonlinear flow routing coefficient for fast interflow | $in.^{-1}\,day^{-1}$ | No | 0 | 1.25 |
| pref_flow_den | Decimal fraction of the soil zone available for preferential flow | — | No | 0 | 5 |
| soil_moist_max | Maximum volume of water per unit area in the capillary reservoir | in. | Yes | **0** | **2.87** |
| snarea_curve | Snow area depletion curve values | — | Yes | **0** | **1** |
| tmax_allsnow | Monthly maximum air temperature at which precipitation is all snow for the HRU | F | No | −10 | 40 |
| tmax_allrain | Monthly minimum air temperature at an HRU that results in all precipitation during a day being rain | F | No | 0 | 90 |

TABLE A2. Summary of VIC parameters considered for calibration. If the parameter is distributed, its calibration is performed on the basis of multipliers. Although description and units refer to actual parameters, the values in boldface represent the multiplier values (instead of actual parameter values).

| Parameter | Description | Units | Distributed | Calibration range Min | Calibration range Max |
|---|---|---|---|---|---|
| binfilt | Variable infiltration curve parameter | — | No | 0.001 | 0.4 |
| Ds | Fraction of Dsmax where nonlinear base flow begins | — | No | $10^{-5}$ | 1 |
| Dsmax | Maximum velocity of base flow | mm day$^{-1}$ | Yes | **0.01** | **2** |
| Ws | Fraction of maximum soil moisture where nonlinear base flow occurs | — | No | $9 \times 10^{-4}$ | 1 |
| depth2 | Thickness of soil layer 2 | m | Yes | **0.5** | **6** |
| depth3 | Thickness of soil layer 3 | m | Yes | **0.5** | **6** |
| newalb | New snow albedo | — | No | 0.7 | 0.99 |
| albaa | Base in snow albedo function (accumulation) | — | No | 0.88 | 0.99 |
| albtha | Base in snow albedo function (melt) | — | No | 0.66 | 0.98 |

TABLE A3. Summary of Noah LSM parameters considered for calibration. If the parameter is distributed, its calibration is performed on the basis of multipliers. Although description and units refer to actual parameters, the values in boldface represent the multiplier values (instead of actual parameter values).

| Parameter | Description | Units | Distributed | Calibration range Min | Calibration range Max |
|---|---|---|---|---|---|
| maxsmc | Soil porosity | m$^3$ m$^{-3}$ | Yes | **0.88** | **1.18** |
| satdk | Saturated soil hydraulic conductivity | m s$^{-1}$ | Yes | **0.41** | **1.39** |
| quartz | Soil quartz content | — | Yes | **0.29** | **1.37** |
| refdk | Used with refkdt to compute runoff parameter kdt | — | No | $2 \times 10^{-8}$ | $2 \times 10^{-4}$ |
| fxexp | Bare soil evaporation exponent | — | No | 0.2 | 4 |
| refkdt | Surface runoff parameter | — | No | 0.1 | 10 |
| czil | Zilitinkevich parameter | — | No | 0.05 | 8 |
| cmcmax | Maximum canopy water capacity used in canopy evaporation | m | No | $5 \times 10^{-5}$ | 2 |
| rsmax | Maximum stomatal resistance | s m$^{-1}$ | No | 2 | 10 |
| lvcoef | Livneh coefficient for adjusting snow albedo | — | No | 0 | 1 |
| slope | Linear coefficient used to compute subsurface runoff | — | No | 0.2 | 1 |

TABLE A4. Summary of Noah-MP parameters considered for calibration. If the parameter is distributed, its calibration is performed on the basis of multipliers. Although description and units refer to actual parameters, the values in boldface represent the multiplier values (instead of actual parameter values).

| Parameter | Description | Units | Distributed | Calibration range Min | Calibration range Max |
|---|---|---|---|---|---|
| maxsmc | Soil porosity | m$^3$ m$^{-3}$ | Yes | **0.88** | **1.18** |
| wind_rp | Empirical canopy wind parameter | m$^{-1}$ | Yes | **0.7** | **1.3** |
| slope_ps | Slope of conductance-to-photosynthesis relationship | — | Yes | **0.7** | **1.3** |
| laimss | Monthly LAI, one sided (spring–summer) | — | Yes | **0.7** | **1.3** |
| fff | Runoff decay factor | m$^{-1}$ | No | 1 | 8 |
| rsbmx | Baseflow coefficient | mm s$^{-1}$ | No | 0.5 | 8 |
| timean | Grid cell mean topographic index | — | No | 7.35 | 13.65 |
| mexp | Exponent used in the curves for the melting season | — | No | 0.5 | 3 |
| z0sno | Snow surface roughness length | m | No | 0.0002 | 0.02 |
| snow_iwc | Liquid water holding capacity for snowpack | m$^3$ m$^{-3}$ | No | 0.02 | 0.06 |
| swemx | New snow mass to fully cover old snow | mm | No | 0.1 | 20 |
| albmin | Minimum snow albedo | — | No | 0.44 | 0.66 |
| albmax | Maximum snow albedo | — | No | 0.68 | 1 |
| albdecay | Exponent in snow decay albedo relationship | h$^{-1}$ | No | 0.001 | 0.1 |

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**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**Cc:** Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Raff, David
**Sent:** 2017-05-11T15:59:06-04:00
**Importance:** Normal
**Subject:** Climate discussion
**Received:** 2017-05-11T15:59:28-04:00

Good Afternoon Again Goks,

[redacted] (b)(5)

[redacted] (b)(5)

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

**To:** Raff, David[draff@usbr.gov]
**Cc:** Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-12T08:03:46-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-12T08:04:13-04:00

Thanks. You have m e reading full time!

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

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**To:** Raff, David[draff@usbr.gov]
**Cc:** Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-12T10:37:44-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-12T10:38:11-04:00
Are models running hot.docx

[redacted]

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
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David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

- IPCC AR5 WG1, Ch9,
    - Page 768, Fig 9.8(a) and Box 9.2: Virtually all models have been running hot over the latest 15-yr period (in that data) despite the fact that the “forecast or non-historical period” (my terminology) is only half that long. It says, “The observed global mean surface temperature (GMST) has shown a much smaller increasing linear trend over the past 15 years than over the past 30 to 60 years (Section 2.4.3, Figure 2.20, Table 2.7; Figure 9.8; Box 9.2 Figure 1a, c). Depending on the observational data set, the GMST trend over 1998–2012 is estimated to be around one-third to one-half of the trend over 1951–2012 (Section 2.4.3, Table 2.7; Box 9.2 Figure 1a, c).” [p. 769.] It notes that the HADCRUT4 trend (the observed trend based on the IPCC’s favored observational set) from 1998-2012 is 0.04 degrees per decade, versus 0.21 degrees per decade for the “full suite of CMIP5 models using RCP4.5. Perhaps more important, it notes that 111 out of 114 realizations exceed the observed trend. [This can be discerned by staring at Fig 9.8(a) long enough, unless you first go cross-eyed.]
    - No less important, the overstatement of the rate of temperature increase has occurred despite the RCP4.5 ensemble using a forcing that seems to be approximately 20% more than what apparently would have been historical. [See AR5 WG1, Annex II, page 1435 (bottom table).]
- Fyfe JC, Gillett NP, Zwiers FW. Overestimated global warming over the past 20 years. *Nature Climate Change*. 2013 Sep 1;3(9):767-9. Available here. In particular, see the first two paragraphs, and Fig 1.
    - Global mean surface temperature over the past 20 years (1993–2012) rose at a rate of 0.14 ± 0.06 °C per decade (95% confidence interval), vs. 0.30 ± 0.02 °C per decade at “at locations where corresponding observations exist”.
    - This mismatch is even greater over the past fifteen years (1998–2012): observed trend, 0.05 ± 0.08 °C per decade vs. the average simulated of 0.21 ± 0.03 °C per decade.
- Karl TR, Arguez A, Huang B, Lawrimore JH, McMahon JR, Menne MJ, Peterson TC, Vose RS, Zhang HM. Possible artifacts of data biases in the recent global surface warming hiatus. *Science*. 2015 Jun 26;348(6242):1469-72A. Available here. This focuses on whether there has been a slowdown in the rate of warming when comparing 1950-2012 vs. 1998-2012 argues that the input data (used for observations, especially for oceans) are biased by past practices. Once Karl et al. corrected for these biases, the discrepancy between the two rates of warming more or less disappears. Without getting into the merits of this paper, note that the temperature trend from the “corrected” data set for 1998-2014 or 2000-2014 is around 0.11 degrees per decade, which is (not quite) half of what the models project (see above).
- Fyfe JC, Meehl GA, England MH, Mann ME, Santer BD, Flato GM, Hawkins E, Gillett NP, Xie SP, Kosaka Y, Swart NC. Making sense of the early-2000s warming slowdown. *Nature Climate Change*. 2016 Mar 1;6(3):224-8. Available here. See Figure 1.
- Medhaug I, Stolpe MB, Fischer EM, Knutti R. Reconciling controversies about the ‘global warming hiatus’. *Nature*. 2017 May 4;545(7652):41-7 (here). See Fig 5. This shows that data through 2015(?) indicates that the discrepancy may have narrowed in the last couple of years but that the models are still on the hot side, but it looks that that data is cutoff during the run-up to the latest El Nino.

**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**Cc:** Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Amanda Erath[aerath@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** David Raff
**Sent:** 2017-05-12T10:55:10-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-12T10:55:19-04:00

Thanks. We'll read as well [redacted] (b)(5)

---

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:
The attached sheet has the citations I was refering to regarding the modeled rate of warming vs. observed rates. [redacted] (b)(5) (b)(5)

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted] (b)(5) (b)(5)

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

**To:** Judy Nowakowski[jnowakowski@usgs.gov]
**Cc:** William Werkheiser[whwerkhe@usgs.gov]; David Applegate[applegate@usgs.gov]; Joanne Taylor[jctaylor@usgs.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-15T11:13:58-04:00
**Importance:** Normal
**Subject:** Re: Climate history brief for Jim Cason
**Received:** 2017-05-15T11:14:27-04:00
INFORMATION.docx

The original was very good. In the Attachment, I have some suggestions to improve it, and sharpen it's focus. Give me a call, if there are any questions. Thanks.

On Wed, May 10, 2017 at 2:50 PM, Judy Nowakowski <jnowakowski@usgs.gov> wrote:

> Hi Goks, attached is the climate history brief. It's long but seems like all good stuff to me, so I thought I'd send it to you and let you decide if there are parts you think can be cut. The 'take away' bullets essentially sum things up, so without those it's a page shorter. Please let me know if you have questions or would suggest revisions. Thanks!

## INFORMATION/BRIEFING MEMORANDUM

DATE: May 11, 2017
FROM: Bill Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations regarding these effects help provide a critical context to support policy makers and resource managers in the Department of the Interior and other agencies in their efforts to be responsible stewards for Federal lands and our Nation's treasures. They can also help provide a basis to anticipate important societal and ecological impacts of future changes in climate and land use.

**KEY TAKEAWAYS**

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in: the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the atmosphere.
- Over millions to hundreds-of-thousands of years, changes in climate are governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), and by variations in atmospheric chemistry.
- During the past 800,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). The current interglacial began about 12,000 years ago. The previous interglacial (which was

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warmer than the current one by as much as X degrees C) ended approximately 114,000 years ago.

- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system cause variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes may occur, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.
- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century was benign relative to the variability seen over the previous thousand years. In particular, within the lands of the United States, there were periods of drought that extended over decades, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest)
- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were much smaller than today. During the last few thousand years, variations in relative global sea level occurred due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers.
    - For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period. They fluctuated between the lows during the Ice

**Commented [GIM4]:** Over geologic time scales, temperatures have ranged from X degrees cooler to Y degrees warmer, and CO2 from W ppm to Z ppm. Is it possible to get a figure that summarizes temperature and CO2 levels over geologic time scales?

**Commented [GIM5]:** It might be useful to include a figure showing sea levels since at least the last glacial max.

**Commented [GIM6]:** Is this correct?

Ages of 190-200 parts per million volume (ppmv) to 280 ppmv during warm interglacial periods. .

Deleted: of the last 800,000 years

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**Temperature Extremes**

The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years.

The Long-Term Geologic Record of Temperature

Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics. In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities; for example, during this time, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to the longer glacial-interglacial periods, air and ocean temperatures still

showed clear variability. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By conducting research at sites throughout North America, USGS scientists aim to determine when the changes began and ended, how widespread they were, and how they influenced communities and habitats.

Instrumental Records of Temperature

Instrumental measurements of land surface and sea surface temperature records have been collected since 1854 (toward the end of the Last IceAge), and the National Oceanographic and Atmospheric Administration (NOAA) has calculated global averages dating from 1880. Typically, temperature anomalies are calculated relative to a 1981-2010 base period or, in the case of global averages, to the 20th century average. Many other surface temperature datasets and analyses are available at NOAA's National Climate Data Center. Historical temperature patterns also are presented by NASA's Goddard Institute for Space Studies (GISS) in a dataset called Surface Temperature Analysis (GISTEMP). This record indicates that warming temperatures have occurred since the first comprehensive records became available in the year 1880, with a higher rate of warming since approximately 1950. Since 1950, land surface air temperature has risen faster than sea surface water temperature. These records indicate that the Earth's average surface temperature has risen about 1.1 degree Celsius (2˚ F) since the late 19th century, which appears to be a larger temperature increase than that of medieval times.

**Hydrologic Extremes**

The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Records of past droughts and unusually wet periods are preserved by tree rings and other archives contained in

**Commented [GIM10]:** Can we say something about the tree line and where it stood relative to today (to the extent known)? See, e.g., MacDonald, G. M., K. V. Kremenetski, and D. W. Beilman, "Climate change and the northern Russian treeline zone," Philosophical Transactions of the Royal Society B: Biological Sciences 363.1501 (2008): 2283-2299.

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**Commented [GIM11]:** 1.Do you mean that current temperatures are higher than they were during the MWP, or that "temperature increase" is higher?
2.Isn't there dispute about this? Also, what about previous warming episodes going back to the Holocene Optimum?

sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events, scientists are examining geologic records of droughts during the last few thousand years. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America. As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographical extent of droughts during the last few thousand years, and how they affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**

Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth of ice sheets were the primary influence on sea level. Sea level is low

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**Commented [GIM13]:** When?

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during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels were 125 meters (410 feet) lower than today.

During the last interglacial period (~125,000 years ago), sea levels were about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example, melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that you see depends on where and when you look. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting them in terms of causes is a priority research area.

**Carbon Cycle Variability**

**Commented [GIM14]:** Might want to consider introducing a figure to show global extent of Ice Sheet and Ocean margins ~20,000 years ago.

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**Commented [GIM15]:** I recommend putting a figure here showing sea level changes since at least the last glacial max. I would also say something about how rapidly sea levels have fluctuated in the past to provide context for changes currently being experienced.

Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where the records extend back 800,000 years, covering the last eight ice ages. Over these long time scales, the $CO_2$ in the atmosphere has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by

**Commented [GIM16]:** Can we say something about biological productivity through geologic time as correlated with CO2 levels?

**Commented [GIM17]:** Why can't we go back further?

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**Commented [GIM18]:** Hasn't the rise in CO2 followed warming in these ice cores?

**Commented [GIM19]:** Curious – Does coastal perimeter make a difference?

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external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released soil carbon into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), but the most significant impacts are observed after European colonists began clearing forests as early as 1700 AD.

**Commented [GIM20]:** Is there any indication of change in accumulation rates since global biological productivity seems to have been enhanced according to recent satellite data possibly due to CO2 emissions, agricultural practices and climate change. See also here. By the way, assuming the latter paper is "correct", doesn't it indicate higher productivity today vs. 1750, despite all the deforestation? Is that correct?

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**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are seeing the results of a broad range of changes(?) that span the history of the Earth. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. The approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

**To:** David Raff[draff@usbr.gov]
**Cc:** Goklany, Indur[indur_goklany@ios.doi.gov]; Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Erath, Amanda
**Sent:** 2017-05-18T17:05:54-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-18T17:09:07-04:00
KRBS_Full_Report_Final.docx

Hello Goks,
Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter). We have made some additions to the uncertainty discussion in section 3.9.1 to specifically address bias correction. Please let me know if you have any questions.

[redacted] (b)(5)

***Amanda Erath***
*Program Analyst*
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

*Office*: (303) 445-2766
*Email*: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted]

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted]

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...

RECLAMATION
*Managing Water in the West*

**Final Report**

# Klamath River Basin Study

**Technical Memorandum 86-68210-2016-06**

**Prepared by:**
**Klamath River Basin Study Technical Working Group**

**U.S. Department of the Interior**
**Bureau of Reclamation**

**State of California**
**Department of Water Resources**

**State of Oregon**
**Water Resources Department**

**March 2016**

## Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Abbreviations and Acronyms

| | |
|---|---|
| AF | acre-feet |
| AFY | acre-feet per year |
| BA | Biological Assessment |
| Basin Study | Klamath River Basin Study |
| BCSD | bias corrected and statistically downscaled |
| BiOp | Biological Opinion |
| BLM | Bureau of Land Management |
| CDFG | California Department of Fish and Game (became CDFW in 2013) |
| CDFW | California Department of Fish and Wildlife |
| CDWR | California Department of Water Resources |
| CEQA | California Environmental Quality Act |
| cfs | cubic feet per second |
| CMIP3 | Coupled Model Intercomparison Project, Phase 3 |
| CMIP5 | Coupled Model Intercomparison Project, Phase 5 |
| COPCO | California Oregon Power Company |
| CRLE | complementary relationship lake evaporation |
| CRS | Congressional Research Service |
| CT | central tendency |
| CVP | Central Valley Project |
| degrees C | degrees Celsius |
| degrees F | degrees Fahrenheit |
| DPS | distinct population segment |
| DRI | Desert Research Institute |
| EIS/EIR | environmental impact statement/environmental impact report |
| ENSO | El Niño/southern oscillation |
| EOM | end of month |
| EPA | U.S. Environmental Protection Agency |
| ESA | Endangered Species Act |
| ET | evapotranspiration |
| $ET_c$ | crop evapotranspiration |
| $ET_o$ | reference evapotranspiration |
| FAO | Food and Agriculture Organization of the United Nations |

| | |
|---|---|
| FERC | Federal Energy Regulatory Commission |
| GCM | general circulation model |
| GDD | growing degree days |
| gpcd | gallons per capita per day |
| HD | hot-dry |
| HDe | ensemble hybrid delta method |
| HUC | hydrologic unit code |
| HW | hot-wet |
| Interior | U.S. Department of the Interior |
| IPCC | Intergovernmental Panel on Climate Change |
| KAF | thousands of acre-feet |
| KBPM | Klamath Basin Planning Model |
| KBRA | Klamath Basin Restoration Agreement |
| KHSA | Klamath Hydropower Settlement Agreement |
| LKNWR | Lower Klamath National Wildlife Refuge |
| M&I | municipal and industrial |
| MODFLOW | modular finite-difference flow (model) |
| MWAT | maximum weekly average temperature |
| NEPA | National Environmental Policy Act |
| NIWR | net irrigation water requirement |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| NWR | National Wildlife Refuge |
| OWRD | Oregon Water Resources Department |
| PDO | Pacific decadal oscillation |
| PDSI | Palmer drought severity index |
| $P_e$ | effective precipitation |
| PET | potential evapotranspiration |
| P.L. | Public Law |
| PM | Penman Monteith dual crop coefficient method |
| Prcp | mean annual precipitation |
| Project | Reclamation’s Klamath Project |
| PRMS | precipitation runoff modeling system |
| Reclamation | Bureau of Reclamation |
| RBM10 | River Basin model-10 |
| RO | runoff |

| | |
|---|---|
| SECURE | Science and Engineering to Comprehensively Understand and Responsibly Enhance |
| SONCC ESU | Southern Oregon/Northern California Coast Ecologically Significant Unit |
| SWE | snow water equivalent |
| Tavg | mean daily average temperature |
| $T_{max}$ | maximum daily air temperature |
| $T_{min}$ | minimum daily air temperature |
| TMDL | total maximum daily load |
| TWG | technical working group |
| UKL | Upper Klamath Lake |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| VIC | variable infiltration capacity (model) |
| WaterSMART | Sustain and Manage America's Resources for Tomorrow |
| WD | warm-dry |
| WW | warm-wet |
| WWCRA | West-Wide Climate Risk Assessments |

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# Chapter 1
# Klamath River Basin Study
# Introduction

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# Contents

# Figures



# Tables

# Chapter 1 Introduction

## 1.1 Background

The Klamath River Basin is the second largest watershed in the State of California (approximately 15,700 square miles), after the Sacramento River Basin (approximately 27,900 square miles; see Figure 1-1). Approximately 60 percent of the watershed is public land (U.S. Geological Survey [USGS], 2007). It supports habitats and numerous fish and wildlife species in addition to supplying water for agriculture, hydropower, recreation, the environment, and tribal, municipal, industrial, and domestic uses. The watershed is divided by the Cascade and Siskiyou Mountains, which create two distinct climates: an arid climate in the upper basin, generally east of the mountains, and a maritime climate in the lower basin. The upper portion of the basin covers approximately 38 percent of the watershed but contributes only 12 percent of the entire watershed's annual flow (Congressional Research Service [CRS], 2005). The lower portion of the basin covers approximately 62 percent of the watershed, yet contributes 88 percent of the watershed's annual flow. The primary tributary inflows are located in the Lower Klamath Basin and include the Shasta, Scott, Salmon, and Trinity Rivers.

The Klamath River Basin has a history of complex water management challenges, dating back more than a century. In large part, these challenges relate to the competing needs of the various mainstem users, irrigation diversions on the Scott, Shasta, and Trinity Rivers (tributaries to the Klamath), and the construction of six mainstem dams (see Figure 1-1), which have altered the natural flow and nutrient and sediment regimes in the river and have inhibited upstream passage of migratory fish above Iron Gate Dam (river mile 190).

Managers of natural resources in the Klamath River Basin have long called for a comprehensive and integrated approach to water management. In 2008, the National Research Council reported that "the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a 'big picture' perspective based on a conceptual model encompassing the entire basin and its many components" (Thorsteinson et al., 2011).

[1] Figure 1-1 produced by Michael Neuman, Klamath Basin Area Office of the Bureau of Reclamation

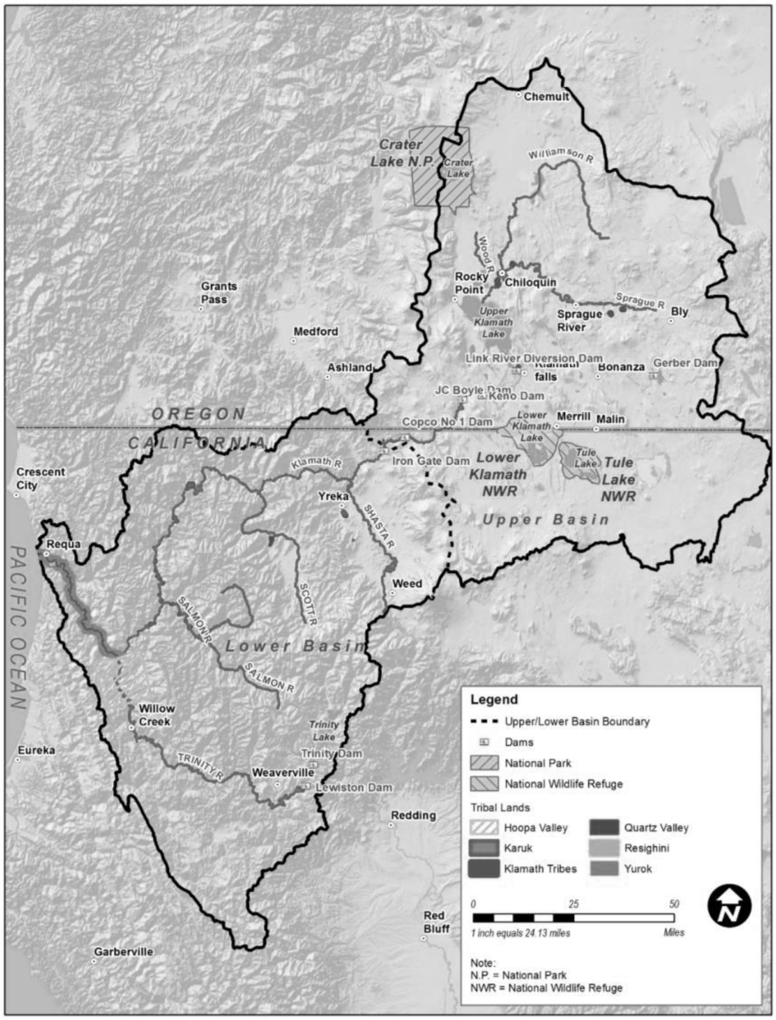


**Figure 1-1. Klamath River Basin overview map**

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to achieve future water security. The Bureau of Reclamation (Reclamation) serves as the U.S. Department of the Interior's (Interior) primary water management agency. It developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (Public Law

[P.L.] 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which was developed as a result. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management.

The Klamath River Basin Study commenced in September 2012. Non-federal cost share partners for the study include the California Department of Water Resources (CDWR) and the Oregon Water Resources Department (OWRD). It should be noted that the Klamath River Basin Study:

- Does not require federal or state environmental review
- Does not contain recommendations for action
- Is not a decisional document

This first chapter of the Klamath River Basin Study provides an overview of the basin, identifies the study purpose, scope, and objectives, and discusses the overall process of the basin study. This chapter also outlines the collaboration and outreach process, which is a significant component of the Klamath River Basin Study.

## 1.2 Purpose, Scope, and Objectives of the Study

The purpose of the Klamath River Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment (WWCRA) but contain additional information, if available (refer to Reclamation [2011d] for water supply assessment; demand assessment is currently under development). The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources west-wide by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build on existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen performance measures

- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The Klamath River Basin has a long history of water management challenges. Numerous studies have been conducted that evaluate the projected impacts of climate change in the region (e.g., Reclamation, 2011; Risley et al., 2012; Oregon Climate Change Research Institute, 2010; National Center for Conservation Science and Policy, 2010) and explore potential adaptation strategies (e.g., increase offstream storage) that may mitigate the impact. The Klamath River Basin Study seeks to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a modeling and decision support framework that allows for exploration of a range of management strategies.

## 1.3 Location and Description of the Study Area

### 1.3.1 Geographic and Geologic Setting

The Klamath River flows over 253 miles from its headwaters north of (and including part of) Crater Lake National Park in Oregon to its outflow at the Pacific Ocean in Requa, California (Figure 1-1). The Klamath River Basin includes all or parts of Klamath, Lake, Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties. Five national forests intersect the Klamath River Basin: Six Rivers, Klamath, Shasta-Trinity, Modoc, and Winema. The Klamath River Basin also contains a substantial amount of land managed by the Bureau of Land Management. From a water management perspective, the basin is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam: the upper portion (hereafter referred to as "Upper Klamath Basin"), and the lower portion (hereafter referred to as "Lower Klamath Basin"). The Upper Klamath and Lower Klamath Basins generally have differing climates and management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake and the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range and Siskiyou Mountains. The primary tributaries to the Klamath River above Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin.[2] The mean annual flow of

[2] Major tributary flow as percentage of Klamath River flow (44%) was reported by BLM (1990) and verified by computing the percentage on a mean annual basis (water years 1951-2012) using the

the Klamath River is about 17,900 cubic feet per second. Eleven miles of the Klamath River between the J.C. Boyle Powerhouse and the California-Oregon border were designated as “scenic” in 1994 under the National Wild and Scenic Rivers System (P. L. 90-452, October 2, 1968). The mainstem lower Klamath River from Iron Gate Dam to the Pacific Ocean, as well as reaches of the Scott River, Salmon River, Wooley Creek (tributary of the Salmon River), and Trinity River, are classified under the National and California Wild and Scenic River Systems (California classifications according to Public Resources Code Section 5093.50 et seq.). These classifications include “wild,” “scenic,” and “recreational.”

The Klamath River contains six mainstem dams (Table 1-1). Link River Dam, at river mile 253 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake. Keno Dam, at river mile 232 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include: California Oregon Power Company (COPCO) 1 dam at river mile 197 (California); COPCO 2 dam at river mile 198 (California), which was constructed to reregulate flows out of COPCO 1; J.C. Boyle Dam at river mile 227 (Oregon), which was constructed primarily for producing peaking power upstream of the COPCO dams; and, Iron Gate Dam at river mile 190 (California). PacifiCorp (owned by MidAmerican Energy Holdings Company) owns and operates the hydropower producing facilities on the Klamath River under Federal Energy Regulatory Commission license 2082 and provides most of the Klamath River Basin’s power (CDWR, 1960).

The Upper Klamath Basin once held pluvial Lake Modoc at an elevation of about 4,200 feet above sea level with an estimated 400 miles of shoreline and 1,000 square miles of surface area. As temperatures warmed during the Late Pleistocene, only Tule Lake, Lower Klamath Lake, and Upper Klamath Lake remained. Parts of the bed of Lake Modoc became Langell Valley and Poe Valley (Beckham, 2006). Lower Klamath and Tule Lakes are discussed further in Section 1.4.2.1. Upper Klamath Basin.

The Klamath River Basin covers three geologic provinces from east to west: the Modoc-Oregon Lava Plateau, the Cascade Range, and the Klamath Mountains. The Modoc-Oregon Lava Plateau includes nearly all of the Klamath River Basin in California east of (and including) Butte Valley. Downstream from Iron Gate Dam and for most of the river’s length to the Pacific Ocean, the river maintains a steep, coarse-grained, confined channel. From Iron Gate east to the Oregon-

---

following streamflow gages: 1) USGS 11530500 Klamath R. nr Klamath, CA; 2) USGS 11522500 Salmon R. at Somes Bar, CA; 3) USGS 11519500 Scott R. nr Fort Jones, CA; 4) USGS 11517500 Shasta R. nr Yreka, CA; 5) USGS 11530000 Trinity R. at Hoopa, CA. This reported value is based on a simplified water balance which may not be an accurate accounting of the contribution of the four major tributaries to flow in the Klamath River at Klamath, CA.

California state line, the river is predominantly nonalluvial and sediment-supply-limited. The Cascade Range forms a north-south belt through the basin, extending from beyond Crater Lake on the north to Mount Shasta on the south. It is bounded in part on the east by the western edge of Butte Valley and on the west by the western edge of Shasta Valley. The Klamath Mountains province includes the entire remainder of the basin lying west of the Cascade Range (CDWR, 1960).

**Table 1-1. Summary of Klamath Basin dams**

| Dam Name | Location | Klamath River Mile | Year Completed | Reservoir Capacity (acre-feet) | Purpose |
|---|---|---|---|---|---|
| **Upper Klamath Basin** | | | | | |
| Clear Lake[1] | Lost River | NA | 1910 | 527,000 | Irrigation |
| COPCO 1 | Klamath River | 197 | 1918 | 6,235 | Hydropower |
| Link River | Klamath/Link River | 253 | 1921 | 873,000 | Control UKL level |
| COPCO 2 | Klamath River | 198 | 1925 | 73 | Hydropower |
| Gerber[1] | Miller Creek | NA | 1925 | 94,300 | Irrigation |
| JC Boyle | Klamath River | 227 | 1958 | 3,377 | Peaking power |
| Iron Gate | Klamath River | 190 | 1962 | 58,000 | Hydropower |
| Keno | Klamath River | 232 | 1966 | 18,500 | Hydropower, recreation |
| **Lower Klamath Basin** | | | | | |
| Dwinnell Dam[2] | Shasta River | NA | 1928 | 50,000 | Water supply |
| Lewiston[2] | Trinity River | NA | 1967 | 14,660 | CVP water supply |
| Trinity | Trinity River | NA | 1962 | 2,400,000 | CVP water supply |

Notes: CVP = Central Valley Project. UKL = Upper Klamath Lake
[1] Clear Lake and Gerber Reservoirs are briefly discussed in Section 4.2.1, Upper Klamath Basin.
[2] Dwinnell and Lewiston Dams are briefly discussed in Section 4.2.2, Lower Klamath Basin.

### 1.3.2 Historical Climate and Hydrology

Mean annual precipitation in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains to the west (Reclamation, 2011a). About two-thirds of the precipitation falls as snow between October and March. The annual long-term average snowfall in Klamath Falls is about 41 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 521 inches of snow annually.

Historical runoff in the Klamath River Basin is highly variable from year to year. Although precipitation predominantly occurs in the winter months, water percolates and moves through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Under natural conditions the Upper Klamath Basin area lakes have a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin

suggests that, although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011c).

All precipitation and snowmelt in the Shasta River watershed (draining to the Klamath River) percolates into the volcanic soil and appears in springs or discharges directly from the ground water into the Shasta River. The only significant surface runoff from the Cascade Range along the eastern edge of Shasta Valley occurs in the Little Shasta River (CDWR, 1960). In the Scott, Salmon, Trinity, and other tributaries of the lower Klamath River, runoff is a function of precipitation and snow storage (CDWR, 1960).

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 degree Celsius, which is 50 percent greater than the global average, as reported by other studies (Knowles et al., 2007; Regonda et al., 2005; Mote, 2008). Further, the Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the mid- and late-20th century. Although observed trends of temperature, precipitation, snowpack, and streamflow in the western United States might be partially explained by anthropogenic influences on climate (Barnett et al., 2008; Pierce et al., 2008; Bonfils et al., 2008; Hidalgo et al., 2009; and Das et al., 2009), these changes are difficult to distinguish from natural climate variability (Villarini et al., 2009), particularly in the case of precipitation (Hoerling et al., 2010). Similarly, future projections of climate over the next 30 to 50 years indicate that the Klamath River Basin will continue to experience warming, as well as increased winter precipitation and decreased summer precipitation. Natural modes of variability like the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO) will continue to influence these general trends (Thorsteinson et al., 2011).

### 1.3.3 Vegetation, Wildlife, and Fish

The Klamath Basin is home to a diverse range of plant species. Tree species include willows, pines, ash, oak, cedar, juniper, alder, and birch. Shrubs range from poison oak and sumac to dogwood, manzanita, honeysuckle, currant, mock orange, ninebark, plum, chokecherry, crabapple, snowberry, sagebrush (several varieties), and Oregon grape. Hundreds of indigenous herbaceous plants grow in this region including orchids, lilies, paintbrushes, grasses, ferns, horsetails, and lichens (Beckham 2006).

Wildlife includes numerous mammals, birds, fish, amphibians, and reptiles. Large animals include black bear, black-tailed deer, mule deer, elk, and mountain lion. Smaller mammals range from beaver, ermine, and fisher to bats, river otter, foxes, squirrels, chipmunks, rabbits, shrews, woodrats, and voles. Numerous reptiles live in the area and include the western rattlesnake, garter snake, and pond turtle. Raptors, game birds, woodpeckers, and other water and land birds are at home in this setting. The Upper Klamath Basin is a part of the Pacific Flyway where hundreds of thousands of migrating birds stop to rest. The U.S. Fish and Wildlife

Service (USFWS) listed the northern spotted owl as threatened under the Endangered Species Act (ESA) in 1990, the shortnose and Lost River suckers as endangered in 1988, and the bull trout as threatened in 1999. The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coast Ecologically Significant Unit (SONCC ESU) of coho salmon as threatened in 1997 and reconfirmed the listing in 2005, and listed critical habitat for the threatened distinct population segment of the Pacific Eulachon in 2011, which includes the Klamath River estuary. In total three plant, eight fish, seven whale, four turtle, four bird species, and one sea lion in the vicinity of the Klamath River are ESA listed; however, the suckers, coho, and bull trout are most often affected by water management practices.

The Lower Klamath and Tule Lake National Wildlife Refuges (NWR), located in the upper Klamath Basin of Oregon and California, encompass approximately 46,700 and 39,100 acres, respectively (Risley and Gannett, 2006). According to the study by Risley and Gannett (2006), mean annual (2003–2005) water use for the Lower Klamath and Tule Lake NWRs was approximately 124,000 and 95,900 acre-feet, respectively, including precipitation and water deliveries.

The Klamath River is home to numerous resident and migrating fish species. Resident fish resources include redband trout and rainbow trout in the mainstem Klamath River (Beckham, 2006). The shortnose and Lost River sucker reside in the Upper Klamath Basin. Historically, the Klamath River was the third most productive river for salmon in the continental United States. Spring Chinook, fall Chinook, and coho salmon, as well as steelhead, spawn in reaches of the Klamath River and its tributaries.

The six mainstem Klamath River dams were all initially constructed without fish passage; therefore, anadromous fish were cut off from the Upper Klamath River reaches above the COPCO 1 dam site in 1918. They were cut off from an additional 7 miles of river, upstream of Iron Gate Dam (river mile 190) in 1962. Two primary hatcheries were established in the Klamath Basin for raising coho, Chinook, and steelhead: the Trinity River Hatchery, built in 1963, and the Iron Gate Hatchery, built in 1966 (CRS, 2005).

Although the COPCO expressed willingness to construct a single fish ladder at COPCO 1, they and the State of California agreed to close off all runs of anadromous fish and to compensate for the loss of natural runs by stocking the lakes and streams of the Klamath Basin with hatchery-raised fish. Most fishery biologists at the time did not believe fish migration over COPCO 1 via fish ladder was feasible (Beckham, 2006).

Because the SONCC ESU of coho salmon is listed as threatened under the federal ESA, the commercial harvest of these fish has been prohibited. In addition, the Chinook salmon harvest has been restricted in northern California and southern Oregon marine waters for several years to allow the Klamath River to attain the Pacific Fishery Management Council’s spawning escapement goals (CRS, 2005).

In 2006 the lack of returning adult salmon to the Klamath River resulted in the closure of several hundred miles of Pacific Coast salmon fisheries (USGS, 2007). Each summer large blooms of the blue-green algae Aphanizomenon flos-aquae in the Upper Klamath Lake lead to low dissolved oxygen and lethal conditions (in part because they produce harmful toxins) for endangered suckers. Major die-offs of suckers occurred in 1986, 1995, 1996, and 1997 (USGS, 2007).

## 1.4 Present Water and Related Resources Development

### 1.4.1 History of Settlement

Indigenous people have inhabited the Klamath River Basin since time immemorial (Beckham, 2006). Currently the basin is home to six federally recognized Indian Tribes: the Yurok Tribe; Hoopa Valley Tribe; Karuk Tribe; the Klamath Tribes, comprised of Klamath, Modoc, and Yashookin; Quartz Valley Indian Community; and Resighini Rancheria (77 FR 47868). Numerous additional native groups that are not federally recognized, such as the Shasta people, inhabit parts of Northern California and Southern Oregon. Although they are not federally recognized, some of them have been inducted into the Karuk Tribe (Beckham, 2006).

The Klamath River and canyon are considered sacred by the native tribes (Bureau of Land Management, 1990). The study area includes burial grounds of the Shasta people and their principal ceremonial areas, which are used for spiritual and educational purposes. Native tribes also value the canyon for other important cultural activities. The river area has long been used for fishing, gathering, and hunting; as a meeting place between the area's various tribes and bands; as shared fishing villages; and as a pathway for inter-tribal exchange and communication (Bureau of Land Management, 1990).

Initial Euro-American explorers in the Klamath Basin included fur traders from the Hudson Bay Company as well as surveyors from the United States Navy and Army and emigrant travelers. Settlement began in the mid-1800s, with the discovery of gold in the Lower Klamath Basin, below the Shasta River confluence (Beckham, 2006). Long-term settlement solidified with the passing of the Homestead Act in 1862, which allowed citizens (or those intending to be naturalized) over 21 years old to settle on 160 acres (or less) of land. Railroad development and logging came later due to the rugged terrain in the southern Cascades and Siskiyou Mountains (Beckham, 2006; CDWR, 1960). The Reclamation Act of 1902 initiated a number of federal irrigation projects across the western United States to manage already existing irrigation and to expand settlement in the arid west. Development of Reclamation’s Klamath Project is described in Section 1.4.2. Water Resources Development.

At one time the Klamath watershed was one of the greatest timber-producing regions in the nation (CDWR, 1960). The Klamath River and tributaries were historically used to transport logs to mill sites. For example, in the late 1800s the

Klamath River Improvement Company drove logs from the Spencer Creek area (west of Keno, Oregon) to the California-Oregon state line. Splash dams made of wood and rock were historically used to create surges of water that would facilitate transportation of logs downstream (Beckham, 2006). The timber industry continues to be a significant portion of the regional economy, despite declines since the late 1970s and early 1980s.

Recreational facilities like campgrounds and trails have drawn many tourists annually into the area including Crater Lake, the Modoc Lava Beds, the Trinity Alps, Marble Mountain Primitive Areas, and the coastal redwoods (CDWR, 1960). River reaches between JC Boyle Dam and Iron Gate Dam, as well as below Iron Gate Dam, are major destinations for commercial and private white-water rafting and kayaking (CRS, 2005).

### 1.4.2 Water Resources Development

#### *1.4.2.1 Upper Klamath Basin*

The passing of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the federal government, led to the development of the Klamath Irrigation Project (Figure 1-2). The initial project was completed in 1907. By 1924 portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region (Reclamation, 2000).

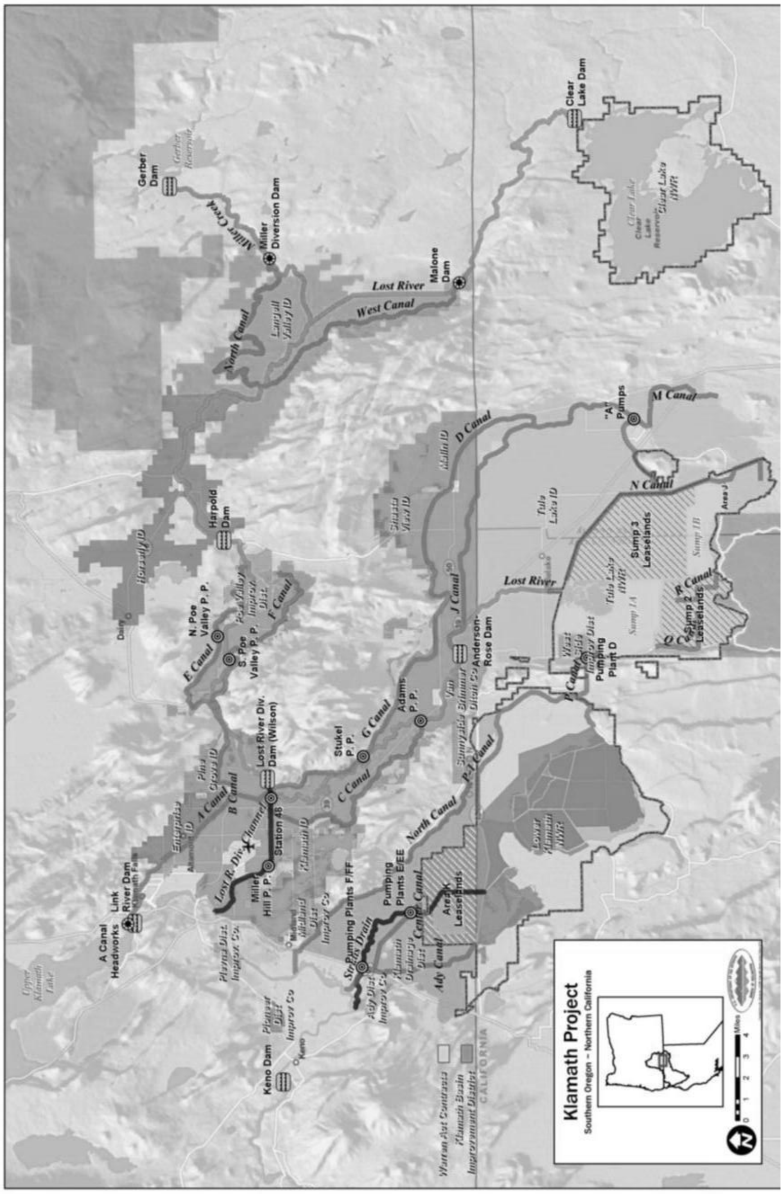


**Figure 1-2. Klamath Irrigation Project map**

Reclamation's Klamath Project is primarily fed by Upper Klamath Lake and the Lost River system, which includes Clear Lake Reservoir on the Lost River and Gerber Reservoir on tributary Miller Creek (refer to Table 1-1). Releases from Clear Lake and Gerber Reservoirs are delivered to the east side of the Klamath Project to irrigate lands in Langell Valley. The Lost River also receives water from Bonanza Springs located in Bonanza, Oregon. During the irrigation season, flows from the springs in the Lost River may be available for irrigation (Reclamation, 2012).

Prior to development of Reclamation's Klamath Project, the Klamath and Lost River Basins were linked by a flood channel, the Lost River Slough, which allowed water from the Klamath River to enter the Lost River and flow to Tule Lake during high runoff conditions. The two watersheds are now linked by the Lost River Diversion Channel, which facilitates water management and surface delivery of water to the Klamath Project, Tule Lake NWR, and Lower Klamath NWR. During the wet periods of the year water is diverted to the Klamath River; during the drier periods irrigation water is diverted to the Lost River from the Klamath River for irrigation needs (Reclamation, 2011a).

Reclamation's Klamath Project has historically included approximately 254,000 acres of land. It provides water to approximately 1,400 farms covering about 200,000 acres as well as about 27,000 irrigable acres of refuge lands. Principal crops raised on Reclamation's Klamath Project include alfalfa, irrigated pasture, small grains, and potatoes. Onions, horseradish, mint, and strawberry plants are also grown (Reclamation, 2011a; CRS, 2005). In 2011 the Klamath Project's gross crop values were estimated at $204 million (Reclamation, 2012). Water released from one of the project's storage reservoirs may be reused several times before it is returned to the Klamath River. Some of the return flows provide water to the Lower Klamath NWR and the Tule Lake NWR. Excess water and water released from NWR lands is returned to the Klamath River via the Klamath Straits Drain.

Additional irrigation in the Upper Klamath Basin occurs in Butte Valley, California, where the Butte Valley Irrigation District supplies water for approximately 4,000 irrigated acres in the southern end of the valley (CDWR, 1960).

#### *1.4.2.2 Lower Klamath Basin*
The Lower Klamath Basin also supports agriculture, but to a lesser extent than the Upper Basin. As of 1997 the number of Lower Basin farms was about 40 percent of those found in the Upper Basin, and agricultural production was estimated to be less than half the value of Upper Basin agriculture ($114 million compared to $283 million) (CRS, 2005).

There are four organized irrigation districts in the Shasta Valley (approximately 10,000 irrigated acres). The Dwinnell Dam, forming Dwinnell Reservoir, or Lake Shastina (Table 1-1), is maintained by the Montague Water Conservation District,

the largest of the Shasta watershed irrigation districts. About 24,000 acres within the Shasta Valley, but lying outside the irrigation districts, are served by individual diversions from various streams (CDWR, 1960). The only known trans-boundary diversion into the Klamath River Basin is from the Sacramento River Basin in California. About 4,000 acre-feet seasonally are diverted into the basin and used for irrigation purposes in the extreme southern end of Shasta Valley.

The Scott River Irrigation District is the single major organized water provider in Scott Valley, California. The district serves approximately 3,500 irrigated acres (CDWR, 1960). Surface water supplies for irrigation are supplemented by pumping of ground water. Most of the irrigated area in Scott Valley, however, lies to the west of the river and is supplied by individual development (CDWR, 1960).

There are additional small cultivated areas in the Lower Klamath Basin, including Hayfork Valley, a portion of the Hoopa Valley Indian Reservation on the Trinity River, and small areas in the vicinity of Lewiston and Seiad Valley (CDWR, 1960).

The Trinity River, the lowermost tributary of the Klamath River, provides water to the California Central Valley Project (CVP), another federal project (CRS, 2005). The Trinity River Division of the CVP was completed in 1964. The Trinity River is the largest tributary of the Klamath River. It enters the Klamath River about 20 miles upstream of its mouth at the Pacific Ocean. The Trinity River Diversion diverts and exports water from the Trinity River system by means of dams, reservoirs, tunnels, and power plants to the Sacramento River (CRS, 2005). At one time, nearly 90 percent of the water in the Trinity River was exported to the Central Valley (CRS, 2005). However, a 2000 Record of Decision reduced that percentage to restore fisheries (CRS, 2005). Lewiston and Trinity Dams (refer to Table 1-1) had cut off 109 miles of anadromous fish habitat on the Trinity River (CRS, 2005).

There are two additional trans-boundary diversions from the Klamath Basin, both in the western portion of the Upper Klamath Basin. One diversion is made from Keene Creek by way of Hyatt Prairie Reservoir, and the other diversion is made from Fourmile Creek by way of the Cascade Canal. This diverted water supplies irrigate lands adjacent to Ashland and Medford in the Rogue River Basin (CDWR, 1960).

### 1.4.3 History of Water Management Challenges

The Klamath River Basin, like many watersheds in the arid western United States, suffers from use beyond the sustainable capacity of the basin (i.e., over-appropriation). This may be due to a number of factors. First, there are physical constraints in the watershed that are unique to the Klamath Basin. Second, federal and state policies with respect to indigenous people and the environment have not been consistent over time, which has contributed to complex

socioeconomic challenges. Finally, regulatory constraints exist in terms of conflicting state and federal policies. This section will briefly describe these constraints as a way of identifying historical and current water management challenges in the basin and to emphasize the need for a comprehensive Klamath River Basin Study to evaluate any identified current and/or projected future imbalances in water supply and demand.

The Klamath River Basin is unique in that the largest agricultural development in the basin occurs in the Upper Klamath, which receives disproportionately low precipitation compared with the rest of the basin. The Upper Klamath Basin has limited suitable sites for reservoir storage; therefore, water users are subject to the effects of climate variability. For example, Upper Klamath Lake, which is the primary source of water for Reclamation's Klamath Project, is relatively shallow and has little carryover storage from year to year, which makes the project highly dependent on current precipitation and snowmelt for water supply (CRS, 2005).

Implementation and enforcement of state and federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for applications for higher use of water supplies over applications for lower use supplies, defined as recreation, industrial, hydropower, and other uses. Water rights adjudication in California was completed for the Shasta River Basin in 1932 and for the Scott River Basin in 1980, but the mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin. Lower Klamath NWR and Tule Lake NWR rely on water from Reclamation's Klamath Project. These refuges have received lower priority for water than irrigators. However, the Lower Klamath NWR (established in 1908) may have federal reserved rights which would advance their priority (CRS, 2005).

Endangered species issues have been an integral component of operating decisions for Reclamation's Klamath Project since the USFWS listed the shortnose and Lost River suckers as endangered in 1988 and the NMFS listed the SONCC ESU coho salmon as threatened in 1997 (CRS, 2005). Management

challenges associated with opposing water needs and policies are illustrated by the events that took place in the early 2000s (described briefly below), which resulted in the largest fish die-off ever recorded in the Klamath River and severe curtailment of irrigation deliveries to Klamath Project irrigators, resulting in economic hardship.

Reclamation is required to comply with the ESA by consulting on the ongoing operations of the Klamath Project with the USFWS and NMFS (the agencies with delegated authority to implement the ESA) to ensure that its operations do not jeopardize listed species or listed or proposed critical habitat. The USFWS has jurisdiction over inland fish and terrestrial species (shortnose sucker, Lost River sucker, and proposed critical habitat for both sucker species). The NMFS has jurisdiction over marine species and anadromous fish (e.g., SONCC ESU coho salmon). In early 2001 a federal district court faulted Reclamation for failing to formally consult with NMFS on the effects of water storage and diversion on downstream coho salmon under its 2000 operating plan, and prohibited Reclamation from making further diversions until it formally consulted on its next (2001) annual plan. Reclamation prepared an operation plan for 2001 which was forecast to be one of the driest years of record. Reclamation prepared a biological assessment (February 13, 2001) which covered operations until April 1, 2001. In April 2001, the USFWS and NMFS each issued final Biological Opinions concluding that Reclamation's proposed operation of the Klamath Project for 2001 would jeopardize the two species of suckers and the population of coho salmon, and it would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from Upper Klamath Lake for coho salmon, while USFWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both Biological Opinions simultaneously, even without providing irrigation water for farmers. A judge's order prevented Reclamation from fulfilling water orders under contracts to the irrigators whenever flows dropped below the minimum flows recommended in the 2001 NMFS Biological Opinion (Reclamation, 2011e).

Reclamation announced its response on April 6, 2001, implementing proposed alternatives that severely limited the delivery of irrigation water. For the 2001 water year, Reclamation stated that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet), but no water would be available from Upper Klamath Lake for deliveries to irrigators or to the Lower Klamath NWR (CRS, 2005). Water conservation measures and higher than expected lake levels later in the summer prompted the Secretary of the Interior to announce that up to 75,000 acre-feet would be released from Upper Klamath Lake to assist farmers. However, this came too late in the season to provide significant assistance.

The National Research Council reviewed the scientific decisions of the controversial 2001 Biological Opinions. The National Research Council Committee concluded that scientific data were insufficient to support the Upper

Klamath Lake level management regimes proposed by the 2001 USFWS Biological Opinion. Although Reclamation's written response to the USFWS 2001 Biological Opinion expressed disagreement with the Biological Opinion's conclusions, Reclamation agreed to not deliver any water from Upper Klamath Lake to Klamath Project water users and NWRs from April through September 2001. Water from Gerber and Clear Lake Reservoirs was used for irrigation on and to meet evaporative losses on the NWR. Releases from Upper Klamath Lake were made to meet minimum stream flows; however, the project was operated to modified minimum elevations for Upper Klamath Lake, which deviated from the minimums prescribed in the USFWS Biological Opinion. An above average number of Chinook salmon entered the Klamath River that August and September, while river flows were unusually low due to drought conditions and unusually warm temperatures. These conditions contributed to the death of more than 33,000 adult salmon (primarily Chinook but also coho, steelhead, and others) due to epizootic disease in the first 40 miles of the river (California Department of Fish and Game, 2004; CRS, 2005).

Several ESA consultations since the early 2000s have affected Klamath Project operations. The most recent to date (and to which current operations adhere) is the 2012 Biological Assessment and 2013 Biological Opinion (BiOp) jointly prepared by the USFWS and NMFS on the Lost River and shortnose sucker, the SONCC coho salmon, the Southern distinct population segment (DPS) green sturgeon, and the Southern DPS eulachon, which directs the operations throughout the Upper Klamath Basin and influences river flows from Link River Dam to the Klamath Estuary. The Biological Assessment and Joint BiOp were completed following a multi-year consultation effort between Reclamation, the USFWS, and NMFS to develop a new long-term operations plan that would "allow Reclamation to continue to operate the Klamath Project to store, divert, and convey water to meet authorized Klamath Project purposes and contractual obligations in compliance with applicable state and federal law while meeting the conservation needs of affected listed species in a coordinated manner" (NMFS and USFWS, 2013).

## 1.5 Future Challenges and Considerations

The Klamath River Basin Study identifies and evaluates potential adaptation strategies to reduce any identified water supply/demand imbalances. Numerous studies have already identified and investigated potential adaptation strategies. To the extent possible, this study builds upon past or existing efforts and encompasses a wide range of options, perhaps even previously rejected strategies that may perform differently under a wider range of evaluation measures.

This study must also consider the regulations that are in place or in progress in the basin, including among other things total maximum daily load (TMDL) water quality criteria established in parts of the watershed, as well as past and existing restoration efforts. For example, this study considers, in a scenario context, the

ongoing negotiations of the Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement and the related Secretarial Determination Process. The following section of this report touches on these considerations in more detail and concludes with recognition of future challenges.

### 1.5.1 Previously Identified Management Alternatives

Numerous studies have been initiated to investigate options for increased or new storage (including groundwater), demand reduction, and habitat restoration, even before the events of 2001 and 2002. The Klamath Basin Water Supply Enhancement Act of 2000 (P.L.106-489) authorized Reclamation to study the feasibility of increasing storage capacity in the Upper Klamath Basin and Reclamation's Klamath Project through surface or groundwater supplies (CRS, 2005). Potential options were identified and developed in the 1990s through the Klamath Basin Water Supply Initiative, a public input process involving potentially affected state, local, and tribal interests as well as concerned stakeholders (for example, potential new storage in the Long Lake Valley [Reclamation, 2010]). The Initial Alternatives Information Report, Upper Klamath Basin Offstream Storage Study (Reclamation, 2011a) further investigated options including an aquifer storage and recovery groundwater option at Gerber Reservoir and a hybrid option involving aquifer storage and recovery at Clear Lake and surface storage at a new dam (to be named Boundary Dam). However, these investigations have not identified viable options from a cost/benefit perspective.

Water banking has also been proposed as a management strategy. During the water shortage of 2001, Reclamation initiated the Groundwater Purchase Program, a water bank to buy water for fish and wildlife (CRS, 2005). As part of the NMFS 2002 Biological Opinion, Reclamation could avoid jeopardizing ESA threatened coho salmon by creating and implementing a water bank. Eligible farmers could bid to irrigate their lands with groundwater from their own wells in exchange for payment, thereby freeing water from Upper Klamath Lake (CRS, 2005). These pilot water bank programs were successful in meeting NMFS Biological Opinion requirements for the 2003 and 2004 water years. Reclamation employed a combination of land idling and groundwater substitution in an attempt to meet water banking targets for 2005–2011; however, in 2006 the court eliminated the water banking requirement that was part of the NMFS 2002 Biological Opinion (Reclamation, 2011). Groundwater pumping has also been identified as a potential long-term water management strategy. Pumping groundwater provides short-term benefits, but over-drafting of aquifers has long-term consequences that are less clear (CRS, 2005).

A number of entities are undertaking specific projects to improve water quality and restore habitat. For example, the U.S. Department of Agriculture's Natural Resources Conservation Service has a Work Plan for Adaptive Management for the Klamath Basin to mitigate the effects of drought on agriculture. The core objectives of this program are: (1) decreasing water demand, (2) increasing water storage, (3) improving water quality, and (4) developing fish and wildlife habitat.

### 1.5.2 Development of Water Quality Criteria

Criteria for TMDLs have been established for the Klamath River Basin (including Lost River) through collaboration between the California North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency (EPA) Regions 9 and 10, and contractors. The TMDLs for the mainstem Klamath River (including an implementation plan for the already approved Lost River TMDL) were approved by the California State Water Resources Control Board and EPA Region 9 in December 2010. NMFS completed its ESA consultation on the Klamath River TMDLs in December 2010 (National Oceanic and Atmospheric Administration [NOAA], 2011). The Oregon Department of Environmental Quality issued a departmental order adopting TMDLs for the listed parameters for the Upper Klamath (Link River Dam to California state line) and the Upper Lost River. The Oregon TMDLs have been submitted to EPA Region 10 for final approval. TMDLs for the Klamath River's major tributaries (Lost, Scott, Shasta, and Trinity Rivers) were previously established. Klamath River Basin TMDLs are summarized in Table 1-2. When TMDLs are developed, water quality criteria are established for sustaining fish and wildlife species, then acceptable waste load allocations are identified. In many cases existing natural conditions exceed established water quality criteria.

**Table 1-2. Summary of Klamath Basin TMDLs**

| Sub-basin or Reach | TMDL |
|---|---|
| Sprague River, Williamson River, Upper Klamath Lake | Dissolved oxygen, chlorophyll a, pH (2002) |
| Lower Lost River (Oregon) | Dissolved oxygen, pH, ammonia toxicity, temperature in Lost River tributaries (2010) |
| Lower Lost River (California) | Nutrients, pH (2008)<br>Temperature (2006) |
| Klamath River (Oregon) | Dissolved oxygen, pH, ammonia toxicity, temperature, chlorophyll a (2010) |
| Klamath River (California) | Nutrients, temperature, dissolved oxygen/organic enrichment (2010) |
| Shasta River | Temperature, dissolved oxygen (2007) |
| Scott River | Temperature, sediment (2006) |
| Salmon River | Temperature (2005) |
| Trinity River | Sediment (2001) |

*Source: EPA, 2008*

### 1.5.3 Past or Existing Restoration Efforts

Numerous programs have been established in an effort to restore natural function of the Klamath River, to the extent possible, and to encourage recovery of the basin's ESA listed species. This section highlights some of these activities; however, it does not attempt to identify all past and present planning activities.

The Klamath River Basin Fishery Resources Restoration Act of 1986 established the Klamath Fishery Management Council to monitor the fish population and recommend annual fish harvest limits, as well as the Klamath River Basin Fisheries Task Force to advise the Secretary of Interior regarding implementation of the Restoration Program (U.S. Government Accountability Office, 2005). A USFWS office was established in Yreka, CA in 1987 to facilitate implementation and management of the Restoration Program (U.S. Government Accountability Office, 2005). However, due to funding constraints the Restoration Program was left to expire in 2006.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 required the NMFS to develop a recovery plan for SONCC ESU coho salmon in 2007 (NOAA, 2011). Since the early 1990s, harvesting of the Klamath River fall-run Chinook salmon stock was restricted offshore from California and Oregon due to low returns. However, based on recent increases in naturally spawning adults, the Secretary of the Interior declared Klamath River fall Chinook salmon populations restored in 2011 (NOAA, 2011).

Additional restoration and recovery actions include construction and monitoring of off-channel ponds (initiated in 2010) to address limited winter rearing habitat for ESA-listed coho salmon. Monitoring efforts following construction showed more than 250 juvenile coho salmon moving into the new ponds in Terwer Creek, illustrating the importance of this habitat for overwintering coho salmon. In 2010 NOAA's Open Rivers Initiative provided funding to the Shasta River Fish Passage Project for removal of the Grenada Irrigation District diversion dam. The Nature Conservancy continues to work on the Shasta River Big Springs Creek to restore more than 11 miles of salmon and steelhead spawning and rearing habitat.

The Trinity River Flow Evaluation (USFWS and Hoopa Valley Tribe, 1999) recommended a restoration strategy for the Trinity River that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids. As a result, the Trinity River Restoration Program strives to restore the natural physical processes in the river and create spawning and rearing conditions (including adequate water temperatures) downstream of the dams that best compensate for lost habitat upstream (Trinity River Restoration Program, 2009).

The federal Wetlands Reserve Program is one of several programs implemented by the U.S. Department of Agriculture. Since the program's inception in 1990, it has resulted in the restoration of approximately 30,400 acres of wetlands in Oregon's Upper Klamath River Basin (Duffy et al., 2011).

Some major Reclamation actions to conserve native fish include construction of a fish screen on the A-Canal, completed in 2003; completion of the Link River Dam fish ladder in 2005; numerous monitoring and research studies; and the removal of Chiloquin Dam on the Sprague River to allow suckers access to historic spawning areas in 2008. The USFWS maintains a habitat restoration program and activities on the NWRs, including walking wetlands. The Nature Conservancy restored 7,000 acres of wetlands at the Williams River Delta of Upper Klamath Lake.

#### *1.5.3.1 Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement*

A large coordinated Klamath Basin restoration planning effort involving 42 Klamath Basin stakeholders began in 2007 and was completed in 2010. The resulting agreement, the KBRA, takes a multi-dimensional approach that attempts to resolve complex problems by focusing on species recovery while recognizing the interdependence of environmental and economic problems in the Basin's rural communities (Klamath Settlement Group, 2009a). The goals of the KBRA include:

- Restoring and sustaining natural production and providing for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin
- Establishing reliable water and power supplies which sustain agricultural uses, communities, and NWRs
- Contributing to the public welfare and the sustainability of all Klamath Basin communities

The KBRA was intended to be implemented alongside the Klamath Hydroelectric Settlement Agreement (KHSA), which lays out the process for conducting necessary additional studies, environmental reviews, and a decision by the Secretary of the Interior (called Secretarial Determination) surrounding the possible removal of the lower four dams on the Klamath River owned by PacifiCorp beginning in 2020. These dams are Iron Gate, COPCO 1, COPCO 2, and J.C. Boyle. The KHSA includes provisions for the interim operation of the dams prior to dam removal, the process to transfer, decommission, and remove the dams, and the transfer of Keno Dam to the Department of the Interior (Klamath Settlement Group, 2009b). On December 31, 2015 the KBRA terminated because federal authorizing legislation was not enacted. The KHSA is still in effect but its interdependent connection to the KBRA requires its amendment to continue. On February 2, 2016 an agreement-in-principle to amend the KHSA was announced between the states of Oregon and California, PacifiCorp, and the US Departments of Interior and Commerce. The ultimate timing of its implementation is not currently known, but the KHSA describes the implementation of the dam removal action in 2020.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a final Environmental Impact Statement/Environmental Impact Report containing 18 alternatives has been completed. Five of the alternatives, including the no project/no action alternative, were carried forward for detailed evaluation. Among the five alternatives carried forward is full implementation of the KHSA and KBRA (Interior and the California Department of Fish and Game, 2011; Thorsteinson et al., 2011).

### 1.5.4 Future Challenges

The primary challenge of the Klamath River Basin Study is determining how to address the uncertainties related to water management in the basin. For example, the fate of the KBRA and KHSA is unknown at this time. Quantification of potential imbalances in current and projected future supply and demand and subsequent evaluation of identified management strategies would yield vastly different outcomes, depending on whether the four lower Klamath River dams are removed and associated restoration efforts move forward. To address this future challenge, the Klamath River Basin Study takes a scenario approach in order to increase flexibility in evaluating climate change impacts on the baseline system.

## 1.6 Collaboration and Outreach

The Klamath River Basin Study is a collaborative effort involving Reclamation and two non-federal cost share partners, the CDWR and the OWRD. The study seeks additional tribal and stakeholder involvement through a process described in the Public Participation and Outreach Plan. The Public Participation and Outreach Plan describes the tribal, stakeholder, and public participation process; however, an overview is provided in this chapter. The process of involving tribes and stakeholders is likely to evolve: consequently the plan will be adapted, as needed, as the study gets underway.

The Klamath River Basin Study was guided by a technical working group (TWG), with input from interested organizations and individuals. The non-federal cost share partners (CDWR, OWRD, and Reclamation) comprise the TWG, which was the primary decision making body for the Basin Study and which conducted a peer review of technical deliverables. Interested organizations and individuals were asked to provide input on the study approach and findings throughout the process. These groups or individuals included federal, state, and local governments; tribes; water use organizations; and non-profit groups. The general public was kept apprised of the progress and findings of the Basin Study primarily through existing public meetings that took place across the region. Figure 1-3 illustrates the Basin Study organization.

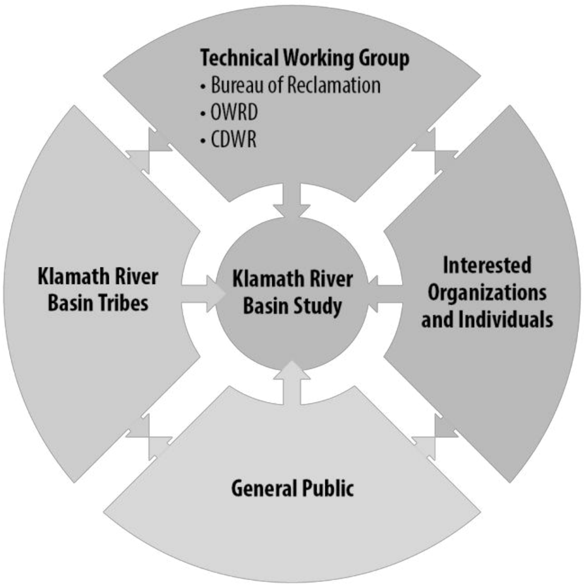


**Figure 1-3. Klamath River Basin Study organizational chart**

## 1.7 What to Expect in this Study

The Klamath River Basin Study, consistent with the Basin Study Framework (Reclamation, 2009), contains four primary components. These are listed in Section 1.2, Purpose, Scope, and Objectives of the Study. They are also illustrated in Figure 1-4, which provides an overview of the basin study approach, highlighting Chapter 1. The first component of the Klamath River Basin Study includes an assessment of current and projected future water supplies. Projected scenarios of future water supply are drawn from methods described by WWCRA (Reclamation, 2011d). However, this study also incorporates climate scenarios from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al., 2012). The Klamath River Basin Study also utilizes streamflow reconstructions from tree-rings to provide a greater variability context for historical climate and hydrologic conditions. This portion of the study evaluates past and projected future changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater if possible.

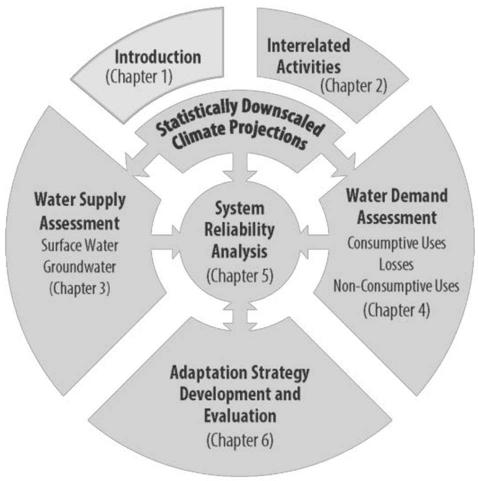


**Figure 1-4. Overall approach for Klamath River Basin Study, highlighting Chapter 1**

The second component of the Klamath River Basin Study includes an assessment of current and projected future water demands. The assessment includes quantification of historical and projected future agricultural demands and open water evaporation. This study takes advantage of newly available demand information through the WWCRA.

The third component of the Klamath River Basin Study includes evaluating the watershed's ability to meet or withstand any identified future water supply/demand imbalances (these may include infrastructure, fish and wildlife, etc.). System reliability is determined by testing the system against various defined performance measures. These measures were developed with input from the Klamath River Basin Study TWG and interested organizations and individuals. This component relies heavily on projections from the first two components of the study (assessment of current and projected future water supply and demand). The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions.

The fourth and final component of the Klamath River Basin Study includes identifying and quantifying potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Adaptation strategies include a range of concepts including operational changes or habitat restoration, among others. In general, the study aimed to identify potential adaptation strategies that that have the potential for reducing water supply/demand imbalances that are likely as a result of climate change.

Adaptation strategies are evaluated using a decision-making framework. Chosen strategies in the Klamath River Basin Study were general in nature in order to evaluate the sensitivity of the basin's water resources to different types of strategies.

The goal for the Klamath River Basin Study is to provide added value to past and ongoing studies to work toward meeting the needs of water users and fish and wildlife in the basin. Further, the Basin Study provides a holistic view of the entire Klamath watershed and does not discount any recommended adaptation strategies. All adaptation strategies identified through the stakeholder and public participation process are included as Appendix E to the Klamath River Basin Study final report.

## 1.8 Supporting Information

The literature synthesis, along with a list of corresponding references, is provided as Appendix A.

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# Chapter 2
# Klamath River Basin Study
# Identification of Interrelated Activities

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# Contents

# Figures

# Chapter 2
# Identification of Interrelated Activities

The Klamath River Basin is unique in that its natural setting and inherent challenges require cooperation among all levels of government and organization. The Klamath River Basin is an interstate watershed with six federally recognized tribes. Three ESA listed fish species are directly affected by water use, and these are being managed by a combination of federal, state, and local efforts. The variety of groups with management responsibilities in the basin has resulted in numerous interrelated activities and coordinated efforts. Following is a brief description of interrelated activities in the Klamath River Basin that are relevant to the Klamath River Basin Study. Also, Figure 2-1 illustrates how Chapter 2 fits into the overall basin study approach.

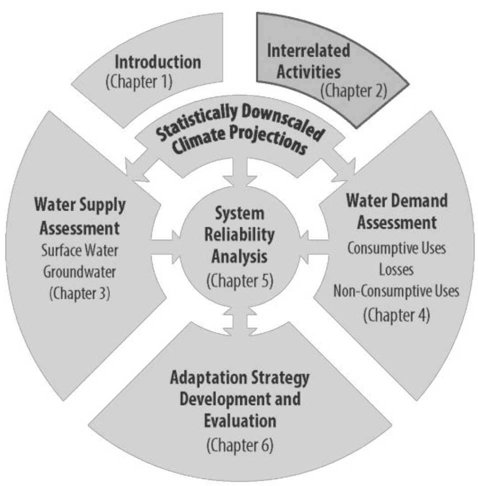


**Figure 2-1. Overall approach for Klamath River Basin Study, highlighting Chapter 2**

## 2.1 Federal

Because the Klamath River Basin contains two federal irrigation projects (Reclamation's Klamath Project and a part of the Trinity River Division), provides habitat for species listed as threatened or endangered under ESA, contains one national park (Crater Lake National Park) and thousands of acres of National Forest and Bureau of Land Management Lands, plus is home to six federally recognized native tribes, numerous past and ongoing federal activities overlap and have common goals. The primary common thread that brings various agencies and activities together is the effort to recover three of the basin's seven ESA listed fish species: the SONCC ESU coho salmon (threatened) and Lost River and shortnose suckers (endangered).

Reclamation's Klamath Project first began providing water to irrigators in 1907, and since then the project has grown to about 254,000 acres of land. The Upper Klamath Basin hydrologic system was significantly altered as a result of:

- wetlands drained from Upper and Lower Klamath and Tule Lakes
- construction of dams and conveyance structures by Reclamation
- construction of seven hydroelectric facilities by PacifiCorp
- a Bureau of Indian Affairs dam on the Sprague River, subsequently removed by Reclamation in 2008
- other water diversions and withdrawals above the Klamath Project

Development in the Klamath River Basin over the last century, including construction of dams without fish passage facilities, has caused declines in anadromous and resident fish species. Their decline was recognized in the early 1980s with passage of the Klamath River Basin Fishery Resources Restoration Act (P.L 99-552), which established the Klamath Basin Restoration Fisheries Task Force and charged it with developing a 20-year Klamath River Basin Conservation Area Fishery Restoration Program. This program was allowed to expire in 2006 and no longer operates; however, numerous restoration projects were implemented over the 20-year period.

Since the listing of three Klamath River Basin fish species under ESA, Reclamation has worked with the NMFS (responsible for SONCC ESU coho salmon) and the USFWS (responsible for Lost River and shortnose sucker) on Klamath Project operations plans that reduce regulated flow impacts to these species (Reclamation, 2011f; Reclamation, 2012a). Due to low water availability in 2001, Reclamation was not able to meet irrigation needs or recommended Klamath River flows and Upper Klamath Lake levels for the ESA listed species. As a result, the National Research Council (charged with advising the federal government on science issues) was directed to review the science underlying

recommendations by the NMFS and the USFWS (National Research Council, 2002; National Research Council, 2004; National Research Council, 2008).

In an interim report completed in 2002, the National Research Council concluded that the recommendations had substantial scientific support except for those regarding minimum lake levels of Upper Klamath Lake and increased minimum flows in the mainstem Klamath River. Also, it found Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows would result in an unknown risk to the population.

In their final report in 2004, the National Research Council corroborated their interim findings and, in addition, provided a broad set of recommendations for the recovery of threatened and endangered species in the entire basin, including expanding the scope of ESA actions by the NMFS and USFWS, planning and organizing research activities and monitoring, identifying specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam which occurred in 2008), identifying information needs related to SONNC ESU coho salmon, and identifying remediation measures that could be implemented based on current information.

Reclamation has conducted numerous studies with the overarching goal of reducing the Klamath Project impacts on the natural river system. These studies include efforts to evaluate potential new off-stream storage facilities, groundwater pumping and aquifer storage options, and water banking mechanisms. Examples of these studies include the Long Lake Valley appraisal report (Reclamation, 2011a), the Upper Klamath Basin Offstream Storage Investigations, Initial Alternatives Information Report (Reclamation, 2011e), the Klamath Project Yield and Water Quality Improvement Options Appraisal Study (Reclamation, 2012e), and the KBRA On-Project Plan (Klamath Water and Power Agency, 2011).

Other federal agencies have also undertaken numerous activities with the goal of managing natural resources for the livelihoods of Klamath River Basin residents while maintaining, as much as possible, the natural ecosystem critical for ESA listed species and others. The Bureau of Land Management (BLM) has conducted watershed analyses for the mainstem Trinity River (BLM, 1990), for which the goal was to compile existing knowledge about various physical processes important in the basin and work toward more holistic ecosystem management. The BLM was also involved in the process to classify reaches of the Klamath River and its tributaries in the National Wild and Scenic Rivers System (BLM, 1990).

The U.S. Forest Service (USFS) conducted a watershed analysis for the Six Rivers National Forest (Orleans Ranger District) in 2003 to support potential watershed restoration actions related to the recovery of ESA listed anadromous salmonid fish species, and to implement fuels reduction around local

communities, municipal water sources, and private lands as outlined by USFS fire plans (USFS, 2003). The Six Rivers National Forest intersects part of the Lower Klamath Basin. The USFS also completed a land and resource management plan (USFS, 1995) for the Six Rivers National Forest, which takes into account impacts to the ESA listed species.

The USFWS and NMFS work cooperatively with private entities to produce habitat conservation plans for incidental take of fish and wildlife species. The USFWS has also been involved in Trinity River Restoration Program efforts to improve the natural function of the Trinity River below Lewiston Dam. For example, they completed the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (USFWS et al., 2000) on the Trinity River Flow Evaluation Study, which resulted in the December 19, 2000 Record of Decision to establish the Trinity River Restoration Program (Interior, 2000).

The NMFS has been involved in a wide variety of interagency efforts, including the development of the SONCC ESU coho salmon recovery plan and working with the North Coast Regional Water Quality Control Board to develop TMDLs for the Klamath River in California. The NMFS has also been involved in a number of habitat restoration projects including construction of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe, and installation of a series of boulder step pools to replace gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners (NMFS, 2009; NMFS, 2011).

The KBRA and KHSA are companion agreements between federal agencies, Klamath Basin Tribes, irrigators, fishermen, conservation groups, counties, the states of Oregon and California, and dam owners, which aim to restore Klamath River Basin fisheries and sustain local economies. The agreements include:

- removal of four dams in the upper Klamath River
- increased flows for fish
- greater reliability of irrigation water deliveries
- reintroduction of salmon above the dams and into and above Upper Klamath Lake
- investment in comprehensive and coordinated habitat restoration
- a power program for Klamath River Basin farmers and ranchers
- mitigation to counties for the effects of dam removal
- investment in tribal economic revitalization

Current Federal Energy Regulatory Commission (FERC) licenses for the dams expired in 2006. These facilities are now operated on annual licenses using existing operating plans. FERC continues to participate in the ongoing process to determine the fate of the dams.

## 2.2 Tribal

Tribal activities in the watershed include the Klamath Basin Tribal Water Quality Work Group, which conducts coordinated surface water sampling activities and participates in the Klamath River Basin monitoring program. The Klamath Basin Monitoring Program is a multi-agency organization aiming to implement, coordinate, and collaborate on water quality monitoring and research throughout the Klamath Basin. As an example, Reclamation and the Klamath Tribes have together been collecting water quality data in Upper Klamath and Agency Lakes since 1988.

The Karuk Tribe and the USFS have coordinated on the land management of the Katimiin Cultural Management Area near Somes Bar, California. Management strategies outlined are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan. The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

Three of the six federally recognized tribes in the Klamath River Basin have supported the KBRA and KHSA agreements (Klamath Settlement Group Communications Committee, 2009a, b). Although the others also strive for ESA listed species recovery and return of the Klamath River to a more natural condition, some have expressed the position that dam removal would occur more immediately if left to the FERC relicensing process.

The Hoopa Valley Tribe worked alongside Interior to lead the Trinity River Restoration Agreement, which aims to mitigate the detrimental effects of decades of out of basin diversions of Trinity River water to Reclamation's Central Valley Project (USFWS et al., 2000). The Hoopa Valley Tribe worked with the USFWS to complete the Trinity River Flow Evaluation Study, which became the basis for the Trinity River Restoration Agreement (USFWS and Hoopa Valley Tribe, 1999). The Yurok Tribe is also a member of the council governing the Trinity Restoration Agreement.

The tribes in the Klamath River Basin have also conducted or commissioned their own studies to quantify the needs of environmental resources on which they depend. For example, Trihey and Associates, Inc. (1996) sought to quantify the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth.

## 2.3 Interstate (including regional)

California and Oregon have coordinated on several activities involving the Klamath River, which flows between the states. The Klamath River Basin Compact was ratified by the states of Oregon and California in April 1957. The compact was meant to facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control of Klamath River water for various purposes. Uses include domestic, irrigation, protection, and enhancement of fish and wildlife, industrial, hydroelectric power production, navigation, and flood prevention.

In addition to water quantity and timing, California and Oregon have coordinated on water quality issues with respect to the development of TMDLs for the mainstem Klamath River and its tributaries. The California North Coast Water Quality Control Board and the Oregon Department of Environmental Quality coordinated on completion of draft TMDLs for respective parts of the mainstem river by 2010. These are both complete and await approval.

PacifiCorps's hydropower facilities in the Klamath River Basin reside in both California and Oregon. As such, California and Oregon have undertaken studies to evaluate effects of these facilities on the environment, as well as potential effects of removal of the dams. For example, the California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios.

## 2.4 State

The Klamath River Basin spans parts of California and Oregon and both states have been involved in management and planning efforts in the basin. In California, the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aims to act as a nexus between statewide planning efforts and local planning, helping to synchronize the large, complex planning processes, regulations, and priorities at the state level with the locally specific issues, data, concerns, planning, and implementation needs at the local level.

The OWRD and CDFW (which prior to January 2013 was the California Department of Fish and Game) have collaborated with federal agencies and tribes on a number of studies. For example, the Instream Flow Study Phase II (Hardy et al., 2006) for the Klamath River, which was developed to help determine flow needs of ESA listed fish species, was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, OWRD, the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. In another example, the USGS and OWRD collaborated in a study to characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options (Gannett et al., 2007).

### 2.4.1 Relationship to State Law including State Water Plan

Water rights adjudications in California and Oregon are in different stages of completion. The Shasta Valley in California was adjudicated in 1932, the Scott Valley in California in 1980. The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court demarking a significant milestone in determining the water rights of the Upper Klamath Basin. The adjudication covers all claims to the use of surface water that predate Oregon's 1909 Water Code. It also covers those referred to as "federal reserved water right" claims. The Circuit will now handle the remaining administrative process prior to issuance of a Court Decree. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the "time immemorial", which may significantly affect water management in the Upper Klamath Basin. The Klamath Tribes have currently agreed not to exercise their rights prior to August 9, 1908. Another significant finding of the Final Order of Determination granted co-ownership of Klamath Project water rights to both Reclamation and Klamath Project water users.

California's water plan update (CDWR, 2013) includes a discussion of activities through the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) as well as a discussion of overall planning activities in the Klamath River Basin. However, most planning activities are carried out by federal agencies and coordinated groups.

Oregon completed its water resources strategy in 2012 and the state legislature has directed that this plan be updated every 5 years (OWRD, 2012). The plan discusses general recommendations for additional groundwater investigations, improved water monitoring, and continued research on the implications of climate change. Like California, Oregon does not direct planning activities in the Klamath River Basin as these are primarily carried out by interagency consortia.

## 2.5 Local

There are numerous local landowner and water user groups within the Klamath River Basin and many of these interact with interagency planning efforts. One example is the KBRA/KHSA planning process, which involves 42 stakeholder groups including local water managers and land owners. Also, the Klamath Basin Rangeland Trust, a nonprofit organization with the mission of improving water availability in the Upper Klamath Basin, was formed in 2002. The Trust facilitates partnerships between private landowners and public agencies to conserve water resources and restore habitat and wetlands.

Local groups are also involved in the Trinity River Restoration Planning efforts, as many of the restoration projects take place using local resources and expertise. For example, the Coordinated Resource Management Plan Group for the South

Fork Trinity River is a consortium of local landowners and various agencies who are interested in water conservation, habitat improvement, and educational outreach in the South Fork Trinity River. The group is funded by the Trinity River Restoration Program. Also, in coordination with the NMFS, Scott Valley Resource Conservation District and local landowners installed a series of boulder step pools to replace gravel push-up dams in the basin.

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# Chapter 3
# Klamath River Basin Study
# Assessment of Current and Future Water Supply

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# Chapter 3 Assessment of Current and Future Water Supply

## 3.1 Introduction

The purpose of the Klamath River Basin Study is to identify current and projected imbalances in water supply and demand across the entire Klamath River Basin, and to develop and analyze adaptation strategies to help resolve any identified imbalances. A system diagram illustrating the primary components of the Klamath River Basin Study is provided in Figure 3-1.

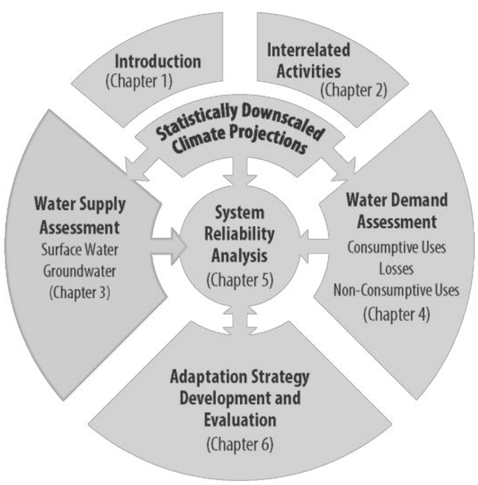



**Figure 3-1. Overall approach for Klamath River Basin Study, highlighting Chapter 3**

The water supply assessment consists of analyses of both surface and groundwater resources, including quantification of historical trends and projections for two future planning horizons, the 2030s (represented as the mean from 2020–2049) and 2070s (represented as the mean from 2060–2089). The water demand assessment (Chapter 4 of the Klamath River Basin Study) consists of analysis of agricultural, tribal/cultural, environmental, evaporative demands, and domestic, municipal, and industrial demands. Statistically downscaled

climate projections provide the basis for the assessments of projected water supply and demand. They are also used directly, along with supply and demand information, to evaluate the river system with respect to environmental demands such as water quality. Current and projected water supply and demand are brought together to evaluate how the river system has responded historically to changes in supply and demand, and may respond in the future as a result of climate change. Potential water supply/demand gaps are evaluated as part of a system reliability analysis. Performance measures are used to analyze system reliability; these are developed through an input process involving Klamath River Basin Study cost share partners, stakeholders, and tribes. The analysis of system risk and reliability is summarized in Chapter 5.

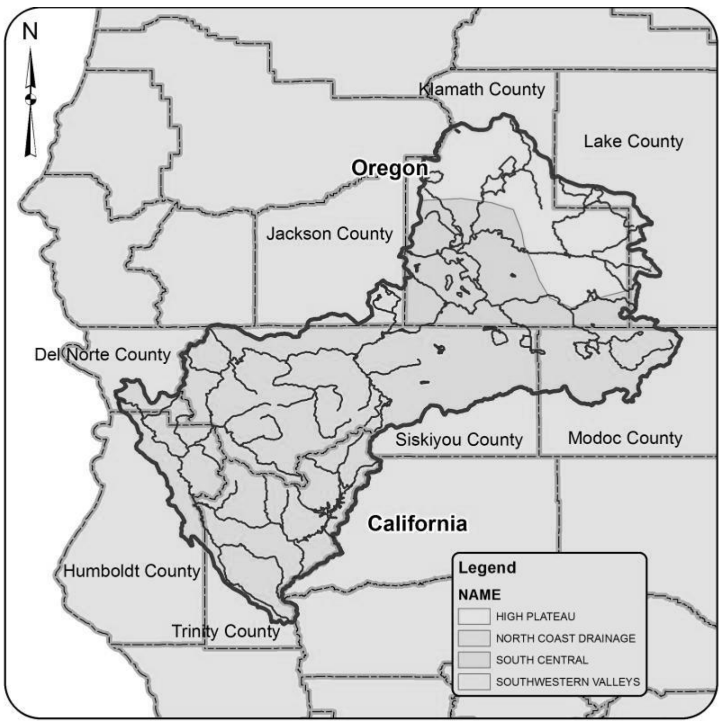
This chapter summarizes the findings of the current and future water supply assessment. The chapter begins with a general discussion of surface and groundwater resources in the watershed, followed by discussions of the technical approach for evaluation of historical water supply (surface and groundwater) and an assessment of historical water supply. The chapter then assesses projected water supply (surface and groundwater), including a detailed discussion of the approach for developing climate scenarios. The assessment of historical and projected surface water supply encompasses the entire Klamath River watershed, while the assessment of historical and projected groundwater supply is focused on three dominant groundwater basins in the watershed: the Upper Klamath Basin, Shasta Valley, and Scott Valley. The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.

## 3.2 Description of Surface and Groundwater Supplies

This section briefly describes the general characteristics of surface and groundwater in the Klamath River Basin. These characteristics provide context for subsequent analysis of historical and projected water supply throughout the watershed. As previously mentioned, surface water supply is analyzed basin-wide, concentrated on three primary regions for analysis of groundwater supply: the Upper Klamath groundwater basin, the Scott Valley groundwater basin, and the Shasta Valley groundwater basin.

The Klamath River Basin is a complex watershed, due in part to its distinct climatic regions and distinct geologic zones which influence surface and groundwater interactions throughout the watershed. The Klamath River Basin spans four NOAA climate divisions, including High Plateau, North Coast Drainage, South Central, and Southwestern Valleys (Figure 3-2). Climate divisions are generally climatically distinct regions; however, they are also defined by political boundaries, as evidenced on Figure 3-2 where climate divisions are separated by the Oregon-California border and, in one case, by county boundaries (the boundary between Southwestern Valley and South Central).

The elevation ranges of Klamath River Basin climate divisions help to illustrate the complexity of the watershed. Basin-wide elevations range from sea level to about 13,600 feet. These two elevation extremes both fall within the North Coast Drainage climate division. The High Plateau ranges between 4,200 feet and 8,500 feet, while the South Central region ranges between 2,870 feet and 8,000 feet. Even the Southwestern Valley Climate Division, which covers only 15 percent of the watershed, ranges between 3,000 feet and 9,040 feet.



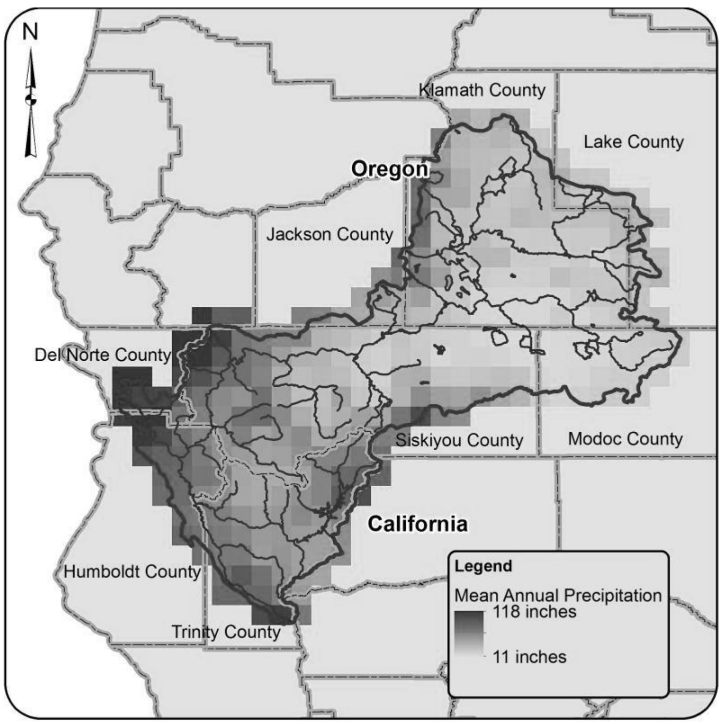

*Source: NOAA, http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html.*

**Figure 3-2. Map of climate divisions within the Klamath River Basin**

Mean annual precipitation and temperature were computed for the three dominant climate divisions within the watershed over calendar years 1950–1999, based on a widely used grid-based meteorological dataset developed by Maurer et al. (2002). This historical meteorological dataset is used as the basis for the historical and projected water supply assessments, as discussed later in this chapter.

Mean annual precipitation varies substantially across the three dominant climate divisions within the watershed (Figure 3-3), from about 24 inches per year in the

South Central to about 44 inches per year in the North Coast Drainage and about 26 inches in the High Plateau. The historical basin-wide mean annual precipitation over the same period is approximately 37 inches per year. Mean annual average temperature varies from almost 41 degrees Fahrenheit (F) in the High Plateau to 43 degrees F in the South Central and about 46 degrees F in the North Coast Drainage climate division, with a basin-wide average of 45 degrees F (computed over the same 1950–1999 period as for precipitation).




*Source: based on meteorological data from Maurier et al., 2002*

**Figure 3-3. Mean annual precipitation (inches/year) over the period 1950–1999**

The seasonality of precipitation and temperature in the Klamath River Basin is typical of coastal watersheds, where the winter season (defined as December through February) experiences the greatest precipitation, about 18 inches per year for this watershed historically (1950–1999), ranging from about 10 inches per year in the South Central to about 11 inches in the High Plateau and 22 inches in the North Coast Drainage. The summer season (defined as June through August) experiences relatively dry conditions, receiving about 2 inches per year for the same period with less than 12 percent of that experienced in the winter, and

ranging from slightly less precipitation in the North Coast Drainage to slightly more in the High Plateau.

Winter temperatures average about 31 degrees F over the historical period 1950–1999 across the basin and range from about 29 degrees F in the High Plateau and South Central to about 33 degrees F in the North Coast Drainage. Summer temperatures average about 60 degrees F basin-wide and range from about 58 degrees F in the High Plateau to about 60 degrees F in the South Central and about 61 degrees F in the North Coast Drainage. Note that diurnal fluctuations in temperature as well as temperatures at different elevations may vary substantially from these daily averages.

**Table 3-1. Summary of Klamath River Basin characteristics**

| | Basin Wide | North Coast Drainage | South Central | High Plateau |
|---|---|---|---|---|
| Mean annual precipitation | 37 inches | 44 inches | 24 inches | 26 inches |
| Mean winter precipitation | 18 inches | 22 inches | 10 inches | 11 inches |
| Mean summer precipitation | 2.1 inches | 1.9 inches | 2.1 inches | 2.4 inches |
| Mean annual daily average temperature | 45 degrees F | 46 degrees F | 43 degrees F | 41 degrees F |
| Mean winter daily average temperature | 31 degrees F | 33 degrees F | 29 degrees F | 29 degrees F |
| Mean summer daily average temperature | 60 degrees F | 61 degrees F | 60 degrees F | 58 degrees F |
| Runoff ratio | 0.46 | 0.52 | 0.27 | 0.24 |
| Elevation range | 0–13,600 feet | 0–13,600 feet | 2,870–8,000 feet | 4,200– 8,500 feet |

### 3.2.1 Surface Water

The Klamath River Basin may be considered a mixed rain and snow influenced watershed. March has historically had the greatest snowpack, averaging about 4.5 inches across the basin (statistics based on historical hydrologic model results are discussed below).

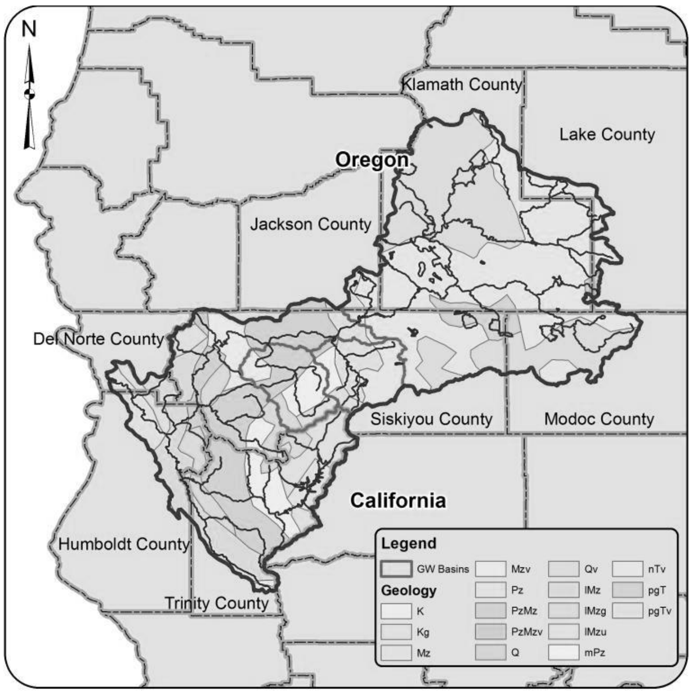
As previously mentioned, the relative magnitudes of key elements of the water balance in the Klamath River Basin vary due to its climatic diversity. Precipitation is one key element of the water balance described above. Other key elements include runoff and evapotranspiration. The ratio of mean annual runoff to mean annual precipitation is an indicator of how much precipitation results in streamflow as opposed to being lost through evapotranspiration or to groundwater recharge. On the whole, the basin has a historical runoff ratio of about 0.46, which translates to 46 percent or almost half of annual precipitation resulting in streamflow. This ratio varies substantially by climate division, from about 0.24 in the High Plateau climate division to about 0.27 in the South Central climate division and 0.52 in the North Coast climate division. In the High Plateau and South Central climate division areas evapotranspiration rates are higher, resulting in lower runoff ratios. In general, over snowmelt-dominated basins of the western

U.S., runoff ratios are typically close to 0.5. Little is known regarding how runoff ratios may change in a changing climate; however, future research may shed light on this question.

### 3.2.2 Groundwater

Groundwater systems are dynamic, with rates of recharge and discharge and hydraulic head varying in response to external stresses. Climate is one primary external influence on groundwater systems, along with human-caused stresses such as pumping, artificial recharge from canal leakage, and other sources. This section offers an overview of three primary groundwater basins to provide context for analysis of historical and projected future conditions in these areas and to provide greater understanding of how climate and other stressors may influence them.

The Klamath River Basin spans numerous geologic formations including volcanic, sedimentary, and granitic (Figure 3-4 and Table 3-2). Each formation, with its various overlying soil types, causes unique surface and groundwater interactions. Groundwater is an important water source for fish, wildlife, irrigators, and residents throughout the watershed, and in particular the Upper Klamath Basin and Scott and Shasta Valleys. For example, it provides cool, late summer streamflows to sustain fish at a critical time for spawning and rearing. In another example, some irrigators depend on groundwater supply to supplement surface water supplies during low water years where surface water supplies may not fully meet water needs, while many more irrigators depend solely on groundwater supplies. Increasing reliance on groundwater makes this an important component of the water supply assessment.




*Source: Generalized Geologic Map of the United States, http://pubs.usgs.gov/atlas/geologic/*

**Figure 3-4. Map of geologic units within the Klamath River Basin**

**Table 3-2. Descriptions of Klamath River Basin geologic types by ID as represented in Figure 3-4**

| ID | Geology | ID | Geology |
|---|---|---|---|
| nTv | Neogene volcanic rocks | lMzu | Lower Mesozoic ultramafic rocks |
| Qv | Quaternary volcanic rocks | mPz | Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks |
| Mz | Mesozoic sedimentary rocks | lMzg | Lower Mesozoic granitic rocks |
| pgTv | Paleogene volcanic rocks | mPz | Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks |
| pgT | Paleogene sedimentary rocks | Pz | Paleozoic sedimentary rocks |
| PzMzv | Paleozoic and Mesozoic volcanic rocks | lMzg | Lower Mesozoic granitic rocks |
| lMz | Lower Mesozoic (Triassic and Jurassic) sedimentary rocks | Kg | Cretaceous granitic rocks |
| PzMz | Paleozoic and Mesozoc sedimentary rocks | K | Cretaceous sedimentary rocks |
| Mzv | Mesozoic volcanic rocks | Q | Quaternary deposits |

As noted previously, the Klamath River Basin Study water supply assessment focuses on three primary groundwater basins including the Upper Klamath Basin, the Scott River Valley (Scott Valley), and the Shasta River Valley (Shasta Valley). The Upper Klamath Basin includes agricultural areas upstream of Upper Klamath Lake and areas in and surrounding Reclamation's Klamath Project, as well as Butte Valley and the Lost River drainage. Each of the three dominant groundwater basins is described below and highlighted in Figure 3-4.

#### *3.2.2.1 Upper Klamath Groundwater Basin*

The Upper Klamath groundwater basin spans about 8,000 square miles upstream of Iron Gate Dam on the Klamath River. Gannett et al. (2012) estimated approximately 500,000 acres of irrigated land for agriculture in 2011. Descriptions of the Upper Klamath groundwater basin primarily come from studies by Gannett et al. (2007) and Gannett et al. (2012).

The Klamath River Basin spans the Cascade Range geologic province (roughly corresponding with the Lower Klamath Basin) and Basin and Range geologic province (roughly corresponding with the Upper Klamath Basin). The Western Cascades sub-province of the Cascade Range constitutes part of the western boundary of the regional groundwater flow system and has very low permeability. The High Cascade sub-province of the Cascade Range consists mostly of volcanic vents and lava flows. There are two main areas in the Upper Klamath Basin with these Quaternary volcanic deposits: near Crater Lake (forming part of the northwest Upper Klamath Basin boundary), and from Mount Shasta east to Medicine Lake Volcano (forming part of the southern Upper Klamath Basin boundary).

Groundwater recharge from precipitation accounts for about 20 percent of the total precipitation in the Upper Klamath Basin. The exact percentage varies spatially and temporally (Gannett et al., 2007). The primary recharge areas in the upper Klamath Basin are the Cascade Range and uplands within and on the eastern margin of the basin. In the northeast part of the Upper Klamath Basin, basalt formations are an important source of recharge due to their high permeability. According to multiple references, at least 60 percent of the inflow into Upper Klamath Lake can be attributed to ground-water discharge in the Wood River sub-basin and springs in the lower Sprague River drainage and the Williamson River drainage below Kirk (Gannett et al., 2007).

Basin and Range Province deposits in the study area include a region from Clear Lake Reservoir eastward to the Upper Klamath Basin boundary. This region generally has low permeability. The region around the Tule Lake sub-basin and to the south consists of major water-bearing volcanic rock from the Late Miocene to Pliocene eras. Rock from these periods consists of volcanic vent deposits and flow rocks. These are generally located throughout the area east of Upper Klamath Lake and Lower Klamath Lake, underlying most of the valley-fill and basin-fill deposits in the study area. The lake deposits near the original lakebeds have much lower groundwater yield due to low permeability and a tendency to

have confining layers. About a mile below J.C. Boyle Dam, a large spring complex contributes significant flow to the Klamath River, on the order of 200 cubic feet per second.

The City of Klamath Falls, which is the primary population center in the Upper Klamath Basin at about 21,000 residents, is entirely supported by groundwater sources. Demand for groundwater has increased in recent decades in the Upper Klamath Basin as a replacement water source for both municipal and agricultural uses.

#### *3.2.2.2 Scott Valley Groundwater Basin*

The Scott River is a major tributary of the Klamath River. The Scott Valley sub-basin consists of 813 square miles, approximately 63 percent in private land and 37 percent in federally managed lands (Harter and Hines, 2008). It is fed by a number of tributaries, many of which become dry in the summer months. CDWR Bulletin 118 (2003), which describes California's primary groundwater basins, characterizes the Scott Valley Groundwater Basin as a narrow alluvial floodplain about 28 miles long and ½ mile to 4 miles wide. The basin boundary is generally defined as the contact between the valley alluvium and rocks from the surrounding mountains, dating from Pre-Silurian to Cretaceous. The CDWR Bulletin 118 groundwater basin within the Scott Valley defines the model domain for the assessment of groundwater supply for this region.

The largest water storage in the watershed occurs in the alluvial fill of the Scott Valley groundwater basin, which is recharged annually by the Scott River and tributary streams, and by infiltration of precipitation and snow melt. This flood plain aquifer area was calculated to represent more than half of the total groundwater stored in the Scott Valley (Mack, 1958). The recent alluvium ranges in thickness from less than one foot to greater than 400 feet in the center of the Scott Valley at its widest point. The thickness of the alluvium decreases both to the north and to the south (Harter and Hines, 2008).

The Scott Valley's largest municipalities, Etna and Fort Jones, use a combination of surface and groundwater sources. Most rural residences use wells, but a few are served by springs and surface diversions (Harter and Hines, 2008). Land use is dominated by agriculture and cattle-raising. Almost 90 percent of the agricultural area within Scott Valley is used for alfalfa and pasture (CDWR, 2000). CDWR (2003) estimates that groundwater use for agriculture and municipal/industrial demand is about 1,300 acre-feet (AF), based on the 1991 flow augmentation survey for Scott Valley (CDWR, 1991).

#### *3.2.2.3 Shasta Valley Groundwater Basin*

The Shasta River is near the size of the Scott Valley and encompasses almost 800 square miles. The agricultural area within the Shasta Valley is comprised primarily of pasture and alfalfa, which amounts to about 80 percent of the total agricultural area. Many sub-basins of the Shasta Valley have pasture/hay and cultivated crops, which together account for more than 10 percent of the land area.

CDWR Bulletin 118 describes the Shasta Valley as having Quaternary alluvium as the primary formation supporting groundwater. This formation appears continuous throughout the valley region. Mack (1960) also reported volcanic rock formations of the western Cascade Mountains and the ancestral Mount Shasta debris avalanche. The southeastern boundary of the watershed is formed by Mount Shasta, one of the few glacier peaks in California. Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (CDWR, 1991). The CDWR Bulletin 118 groundwater basin within the Shasta Valley defines the model domain for the assessment of groundwater supply for this region.

The hydrology of the Shasta River has been and continues to be affected by Dwinnell Dam (built in 1928 and raised in 1955), surface water diversions, and interconnected alluvial groundwater pumping. Domestic, municipal, and industrial water use information available for the Shasta Valley, which had a population of 18,225 based on the 2000 Census, primarily consists of urban water management plans for the cities of Yreka and Weed, California. Water supply for the City of Yreka, with a population of 7,765 according to the 2010 Census, is completely sourced from surface water. The water supply for Weed, with a 2010 population of 2,967, is comprised of springs and wells.

## 3.3 Historical Surface Water Availability

This section summarizes historical and current surface water availability in the Klamath River Basin. Specifically, it provides a brief discussion of previous studies, a discussion of data and models used, and an analysis of historical availability and trends. Although the literature synthesis (Appendix A of the Klamath River Basin Study Report) contains a detailed discussion of previous studies, this section touches on those related to historical water supply availability to provide context for the assessment of surface water supplies.

### 3.3.1 Previous Studies

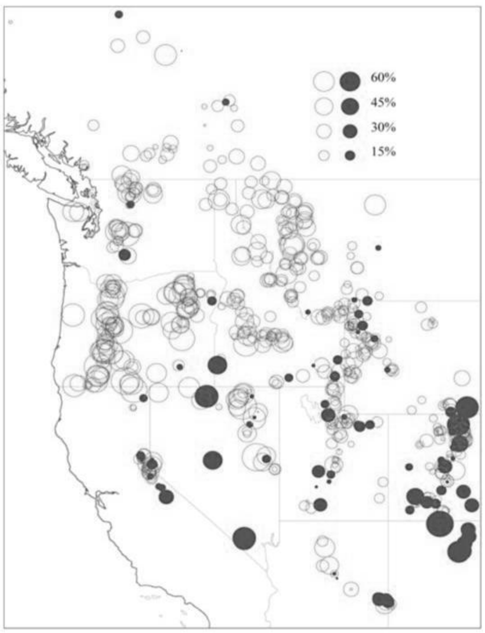
Numerous studies conducted over regions including northern California show increasing trends in historical temperatures, both annually and seasonally (Bonfils et al., 2007; Cayan et al., 2001; Dettinger and Cayan, 1995). Temperature increases over the 20th century have been estimated at 1.7 degrees F (1895–2011 over California by Moser et al., 2012) and 0.2–1.5 degrees F (difference between

1991–2007 and 1961–1990 over Shasta-Trinity National Forest by Furniss et al., 2012). Historical trends in precipitation have been inconsistent. Furniss et al. (2012) found no apparent increase in precipitation variability, but found an increase in winter, defined as January and February (0.1 to 7.9 inches) and growing season precipitation (0.1 to 2.1 inches). Research has shown small increasing trends in the frequency of historical extreme events over the mid-Pacific region (Kunkel, 2003; Madsen and Figdor, 2007; Gutowski et al., 2008).

Historical trends in snowpack and runoff over Northern California include declines in spring snowpack and earlier snowmelt runoff (Knowles et al., 2007; Regonda et al., 2005; Peterson et al., 2008; Stewart, 2009; Furniss et al., 2012; Reclamation, 2011c). However, glaciers on Mount Shasta are among the few in the world that are increasing in size (Furniss et al., 2012). Note that any trends in climate and water balance (i.e., snowpack and runoff) are dependent on the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k).

In the Upper Klamath River Basin, dry season (April to September) and summer streamflow (July to September) declined 16 percent and 38 percent, respectively during the period between 1961 and 2009 (Mayer and Naman, 2011). This decline is closely associated with decline in April 1 snowpack, which decreased approximately 40 percent during the same study period for snowcourse sites located below 1820 meters (5,970 feet) in elevation.

In response to temperature increases in the Pacific Northwest (Cayan et al., 2001; Regonda et al., 2005), snowpack in western North America has declined over the past 50 years (Mote et al., 2008). Figure 3-5 illustrates declines in April 1 snow water equivalent (SWE) at 594 locations in the western U.S. and Canada between 1950 and 2000. Mote et al. (2008) noted that the Pacific Northwest (generally including Washington, Oregon, and Idaho) has experienced the largest decline in snowpack in the western U.S. Although many regions have experienced decreasing trends, some regions have experienced increasing trends in April 1 SWE, namely in parts of the southwestern U.S.




*Source: Mote et al., 2008*
Note: Negative trends are shown by open red circles, positive trends by solid blue circles.

**Figure 3-5. Relative trends in April 1 SWE at 594 locations in the western U.S. and Canada, 1950–2000**

Attribution studies have aimed to distinguish historical trends due to climate change versus trends due to natural climate variability (Bonfils et al., 2007 and Cayan et al., 2001 for the western United States; Gershunov et al., 2009 for California and Nevada). Bonfils et al. (2008) found that increases in daily minimum and maximum temperatures over 1950–1999 cannot be fully explained by natural climate variability. Pierce et al. (2008) found that climate change may be the cause of about half of reductions in the fraction of annual precipitation falling as snow observed in the western United States from 1950 to 1999. The strongest changes in winter runoff, and in the fraction of precipitation accumulated as snow, have occurred at medium elevations (750–2,500 meters or 2,460–8,200 feet and 500–3,000 meters or 1,640–9,840 feet, respectively) close to freezing level. These are not likely to be associated with natural variability (Hidalgo et al., 2009). Barnett et al. (2008) found that, over the western United States, up to 60 percent of the climate-related trends in streamflow are human induced. These as well as other attribution studies of streamflow timing (Hidalgo et al., 2009 and Das et al., 2009) and snow/rain days (Das et al., 2009) show that statistical significance of the anthropogenic signal is greatest at the scale of the

western U.S. and weak or absent at the watershed scale, except in the Pacific Northwest (Hidalgo et al., 2009). However, attribution of any apparent trends in precipitation to climate change remains difficult (Hoerling et al., 2010).

### 3.3.2 Approach

The general approach for assessing historical surface water supply in the Klamath River Basin is to evaluate how historical climate has influenced the quantity, timing, and form of precipitation falling on the landscape. Assessment of historical water supply involves (1) evaluating trends in historical climate using a widely used spatially distributed meteorological dataset; (2) utilizing a hydrologic model to simulate the partitioning of precipitation into snow storage, evapotranspiration, runoff, and recharge to groundwater based on meteorological inputs and landscape characteristics; and (3) evaluating trends in historical water balance parameters based on hydrologic model simulations. This overall approach is illustrated by Figure 3-6.

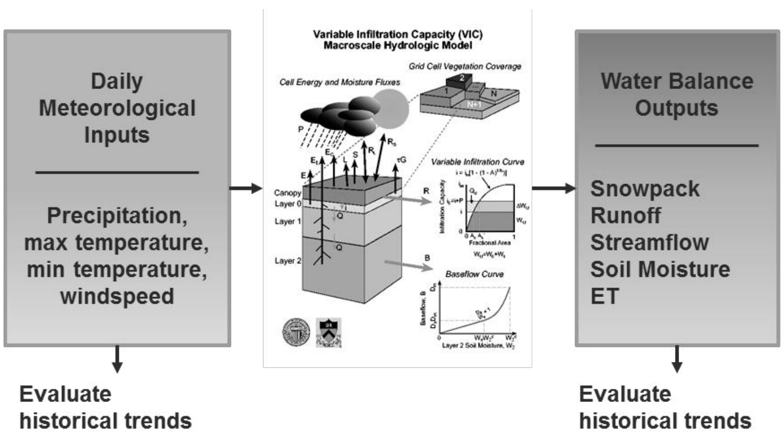



**Figure 3-6. Summary of approach for assessment of historical surface water availability**

For the Klamath River Basin Study, current and future water supply assessments rely on the variable infiltration capacity (VIC) model for simulation of surface water hydrology. The VIC model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) is a grid-based hydrologic model that solves the water balance at a spatial scale of 1/8$^{th}$ degree, or approximately 10 kilometers on a side. Details regarding the VIC model and the configuration used in the Klamath River Basin water supply assessment are provided in Appendix B, Supplemental Information for Assessment of Water Supply; however, details relevant to this study are provided below.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate water balance variables. The Klamath River Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period from January 1949 to July 2000. Additional model forcings that drive the water balance, such as solar (short-wave) and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficit, are calculated within the model.

The VIC model outputs may be defined by the user, but typically include grid cell water balance terms such as evapotranspiration, baseflow, or runoff. Gridded surface runoff and baseflow are hydraulically routed to produce streamflow at a select group of locations, using the model presented by Lohmann et al. (1996). Routed streamflow using this approach represents natural streamflow – that is, streamflow that would occur in the absence of water management (i.e., diversions, return flows, and storage). For climate change impact studies, VIC is commonly run in water balance mode due to its higher computational efficiency compared to the alternative energy balance mode, which facilitates numerous projected climate simulations.

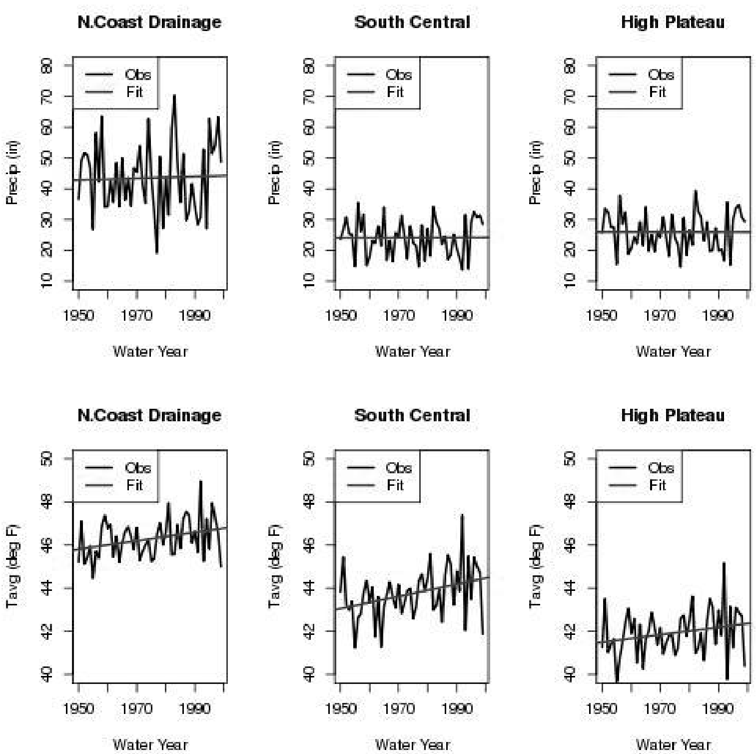
### 3.3.3 Present Availability and Historical Trends

This section summarizes present climate and surface water availability as well as historical trends. Historical simulated trends in climate and water balance variables are based on data used in the Klamath River Basin water supply assessment. The trends presented for climate (precipitation and temperature) likely have less uncertainty than those based on water balance parameters, primarily because climate trends were computed based on interpolated observations whereas water balance trends were computed based on hydrologic model output. Where appropriate, results are compared with findings from previous studies.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. For example, this dataset was used to develop climate and hydrologic projections developed and supported by Reclamation as part of its West-Wide Climate Risk Assessment (Reclamation, 2011d) and data portal (Archive Collaborators, 2000). The dataset has been extended beyond the original July 2000 date to December 2010 (Maurer et al., 2010). However, we utilized the original dataset as the basis for evaluating historical hydrology in the region to maintain consistency with previous efforts.

Historical trends in April 1 SWE, total annual runoff, total annual evapotranspiration, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model described briefly in the previous section. Because summer months typically receive low precipitation in the Klamath River Basin (see Table 3-1), soil moisture is an important water source

for natural vegetation and perhaps some dryland agriculture. Hence, the Klamath River Basin Study Water Supply Assessment reports trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed. Trends were computed over the entire Klamath River Basin, as well as over the three dominant climate divisions within the basin: North Coast Drainage, South Central, and High Plateau. The fourth climate division within the watershed, Southwestern Valleys, covers only a small portion of the watershed (spanning just five spatially distributed VIC model grid cells). Therefore, data for this region is not summarized.




Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

**Figure 3-7. Trends in mean annual water balance parameters (precipitation and temperature) over 1950–1999 water years**

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50-year period), small but increasing trends over the portions of the basin within the North Coast Drainage and South Central Climate Division (about 1.3 inches [+3 percent] and +0.1 inches [+0.5 percent] over the 50-year period, respectively), and a small decreasing trend over the portion of the basin within the High Plateau Climate Division (-0.03 inches [-0.1 percent]). None of these historical trends is statistically significant at the 95th percentile level (see Figure 3-7 and Table 3-3 for a summary of trends). The combination of both increasing and decreasing historical trends in precipitation over parts of the watershed is consistent with previous findings (Hoerling et al., 2010) showing a lack of clear historical change signal for annual precipitation.

All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999 (Figure 3-7 and Table 3-3). The trends in those portions of the basin within the North Coast and South Central climate divisions, as well as in the basin as a whole, are statistically significant at the 95th percentile level. Historical trends in mean annual temperature (+1 degree F basin-wide and +0.8 to +1.4 degrees F, depending on the climate division) are consistent with previous findings indicating positive change in temperature (Moser et al., 2012; Furniss et al., 2012).

Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide as well as for each of those portions of the basin within the North Coast, South Central, and High Plateau climate divisions (see Figure 3-8 and Table 3-3). Historical trends basin-wide indicate about a 41 percent decrease in April 1 SWE, with a range of about 22 percent to 45 percent over the portions of the basin within the three dominant climate divisions. The range of historical decreases in SWE computed by this study closely corresponds with the reported decrease in Upper Klamath Basin April 1 SWE by Mayer and Naman (2011) of 40 percent over the period 1961–2009, using snow course measurements below about 6,000 feet. Although the computed declines in April 1 SWE may be considered substantial, none are statistically significant at the 95th percentile level.

Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent, with a range of 4 to 22 percent depending on the climate division (see Figure 3-8 and Table 3-3). Mayer and Naman (2011) reported larger declines in streamflow over the 1961–2009 period (16 to 38 percent), albeit over spring and summer months only. None of the computed trends in runoff (regional or basin-wide) are statistically significant at the 95th percentile level.

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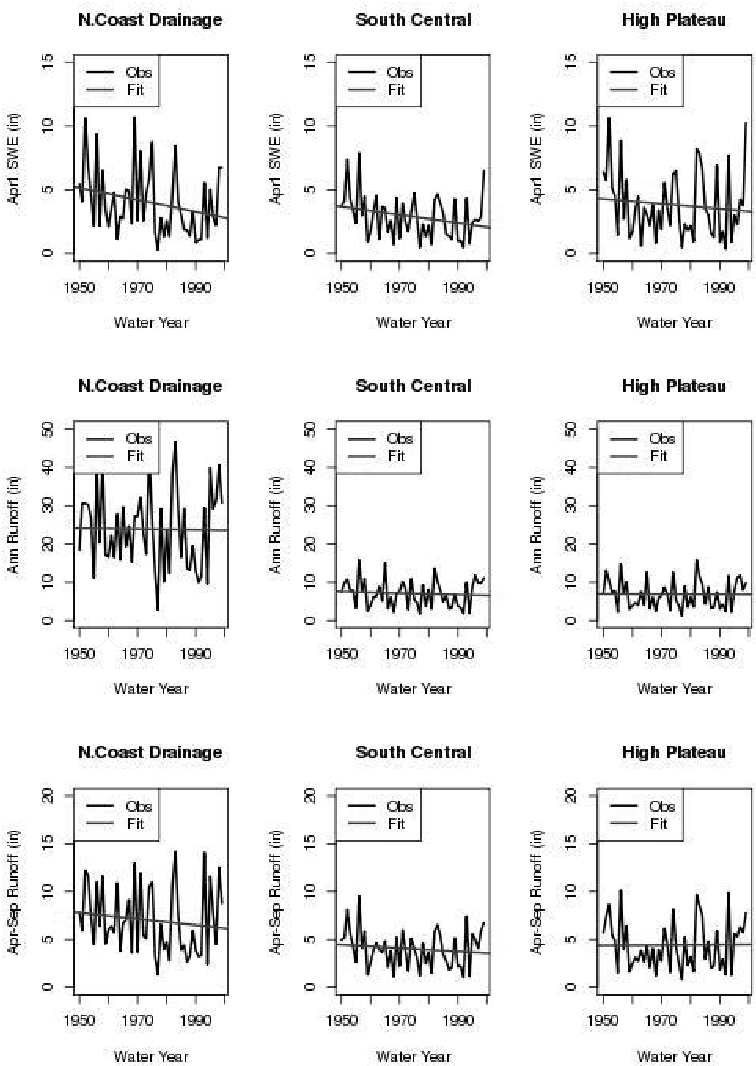
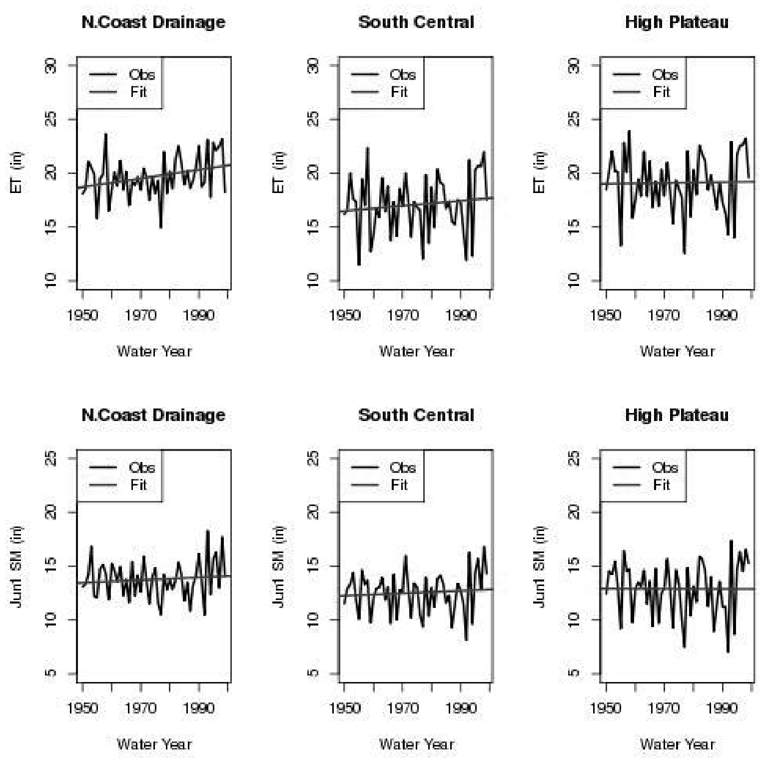



Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

**Figure 3-8. Trends in mean annual water balance parameters (April 1 SWE, annual runoff, and irrigation season runoff) over 1950–1999 water years**

Evapotranspiration (ET), as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide (see Figure 3-9 and Table 3-3). Portions of the basin within the three dominant climate divisions indicate a range of increase from about 1 percent in the High Plateau region to 11 percent in the North Coast Drainage region. The increase in ET is statistically significant at the 95th percentile level for the North Coast Drainage climate division only.




Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

**Figure 3-9. Trends in mean annual water balance parameters (annual evapotranspiration and June 1 soil moisture) over 1950–1999 water years**

Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole, yet the trends by climate division range from a decrease of about 0.3 percent in the High Plateau region to an increase of 5 percent in the South Central region and an increase of 4 percent in

the North Coast Drainage region (Figure 3-9 and Table 3-3). These trends are not statistically significant at the 95th percentile level.

**Table 3-3. Mean change over 1950–1999 period (water years) by climate division within the Klamath River Basin and basin wide**

| | Basinwide | | N Coast Drainage | | South Central | | High Plateau | |
|---|---|---|---|---|---|---|---|---|
| **Precip** | +0.8in | +2% | +1.3in | +3% | -0.1in | +0.5% | -0.03 in | -0.1% |
| **Tavg** | **+1°F** | **--** | **+1.0°F** | **--** | **+1.4°F** | **--** | **+0.8°F** | -- |
| **April 1 SWE** | -2.0in | -41% | -2.3in | -45% | -1.6in | -42% | -1.0 in | -22% |
| **Annual Runoff** | -0.5in | -7% | -0.5in | -6% | -0.6in | -22% | -0.1 in | -4% |
| **Apr-Sep Runoff** | -1.2in | -18% | -1.6in | -20% | -0.9in | -19% | +0.1in | +2% |
| **Annual ET** | +1.5in | +8% | **+2.0in** | **+11%** | +1.2in | +7% | +0.2 in | +1% |
| **June 1 Soil Moisture** | 0.4in | +3% | +0.6in | +4% | +0.6in | +5% | -0.03 in | -0.3% |

Note: Numbers in bold indicate statistical significance of trends at the 95th percentile level.
Precip =mean annual precipitation/ Tavg = mean daily average temperature; SWE = snow water equivalent; ET = evapotranspiration

As previously mentioned, computed trends are highly dependent on the time period over which they are calculated. The primary reason for the dependence on duration is that, coincident with the low frequency trends resulting from human-induced climate change, there are various patterns of natural climate variability. Temporal patterns of climate variability in the Northwest are strongly influenced by variations over the Pacific Ocean, chiefly El Niño/Southern Oscillation (ENSO). ENSO involves linked variations in the tropical Pacific Ocean and overlying atmosphere. During the El Niño phase of ENSO the wintertime jet stream tends to split, with warmer air flowing into the Northwest and Alaska and a southern branch of the jet stream directing unusually frequent and heavy storms toward southern California. During the El Niño winter and spring, Oregon's climate is slightly more likely than usual to be warm and dry. The Pacific Decadal Oscillation (PDO) is another pattern of climate variability that acts similarly to ENSO, but typically over longer time frames (on the order of multiple decades). Depending on the time period chosen for trend analysis, patterns of natural climate variability may mask or

## Historical Surface Water Availability

Of historical precipitation, temperature, snowpack, runoff, evapotranspiration, and soil moisture, the only statistically significant trends at 95th percentile level are:

Temperature (all regions) and evapotranspiration (North Coast Climate Division).

amplify the apparent trends due to human-induced climate change. Choosing longer time periods over which to compute historical trends can help to reduce the relative influence of natural climate patterns on the computed trends.

## 3.4 Historical Groundwater Availability

For analysis of groundwater impacts of climate change, outputs from surface water hydrology simulations, informed by climate projections, may be used as inputs to groundwater models. For the Klamath River Basin Study, groundwater hydrology is simulated using the USGS MODFLOW, or moderate finite-difference flow model, over the Upper Klamath Basin (upstream of Iron Gate Dam), developed through studies by Gannett et al. (2007, 2012). This model simulates evapotranspiration, groundwater head, and discharge to streams, among other things. Groundwater hydrology is also simulated in the Scott and Shasta Valleys using a multiple regression-based tool. This groundwater simulation tool performs an overall water balance to simulate relative groundwater levels. This modeling tool may be used to evaluate projected changes in the overall water balance of these river systems, as well as to evaluate the effects of projected changes in streamflow on the groundwater system.

### 3.4.1 Previous Studies

Groundwater modeling studies have been previously conducted for parts of the Klamath River Basin including the Upper Klamath Basin (Gannett et al., 2007, 2012) and the Scott River Valley (S.S. Papadopulos & Associates, Inc., 2012). Additional groundwater modeling efforts are currently underway, including research studies in the Scott and Shasta Valleys by faculty and graduate students at the University of California at Davis (Harter and Hynes, 2008). These studies are further described below.

#### *3.4.1.1 Upper Klamath Basin*

Gannett et al. (2007, updated in 2010) completed a groundwater investigation of the Upper Klamath Basin, upstream of Iron Gate Dam, to improve understanding of the groundwater dynamics in the region. The investigation was based on collected data, monitoring, and analysis. Since 2001 the basin has experienced increased groundwater pumping, particularly within and near Reclamation's Klamath Project, in response to various biological opinions and court orders. A water bank program administered by Reclamation, as well as subsequent Klamath Water and Power Agency Water Use Management Plans, have purchased varying quantities of groundwater to supplement surface water in 8 of the past 11 years (2003 through 2013). The water bank provided incentives for irrigators to increase groundwater pumping during years of low surface water availability as a pathway for retaining greater instream flows.

In a subsequent study by Gannet et al. (2012), in collaboration with the OWRD and Reclamation, a MODFLOW finite-difference groundwater model was developed to represent the system and to improve understanding of the long term

effects of the above-described water banking program. In this investigation, the authors sought to identify the optimal strategy for meeting user needs while not exceeding defined impact constraints. This study found that some supplemental groundwater pumping could occur while not exceeding defined constraints, and that groundwater levels should recover from the observed declines if pumping was reduced to pre-2001 rates.

#### *3.4.1.2 Scott Valley*

A groundwater study for the Scott Valley (tributary region to the Klamath River, see Figure 3-13) was completed by S.S. Papadopulos & Associates, Inc. in 2012 for the Karuk Tribe. The study examined the impacts of groundwater pumping on the aquifer and on the Scott River by evaluating groundwater levels under three scenarios including recent use conditions, an alternative water use condition representing partial build-out of the existing groundwater capacity, and partial build-out with gradual increases in pumping levels.

Results from the study indicated that long-term declines in groundwater levels were minimal in winter and greater in late summer, corresponding with seasonal groundwater pumping. The declines can, and have, impacted streamflows. The model was used to develop a relationship between groundwater levels and stream depletions, showing that increases in groundwater pumping result in reductions in streamflow mostly within the first year or two (S.S. Papadopulos & Associates, Inc., 2012).

Researchers at the University of California, Davis completed the Scott Valley Community Groundwater Study Plan (Harter and Hynes, 2008, hereafter referred to as the UC Davis Groundwater Study Plan), which discusses the motivation for the approach of their ongoing groundwater modeling study for the Scott Valley. The study is being conducted in cooperation with Siskiyou County and Scott Valley stakeholders as a result of recommendations made in the TMDL Action Plan (State of California, 2005) and the Scott River Watershed Council Strategic Action Plan (Scott River Watershed Council, 2005). The State of California has determined that the water quality standards for the Scott River are exceeded due to excessive sediment and elevated water temperature. Studies on which the TMDL Action Plan is based state that groundwater inflows are a primary driver of stream temperatures in the Scott Valley, along with human-caused changes in riparian shading.

The UC Davis Groundwater Study Plan identifies a number of statements, hypotheses, and research questions that will be addressed during the study. A couple of noteworthy statements include: (1) there is a statistically significant correlation between SWE, total annual precipitation, and average Scott Valley groundwater table elevation in subsequent months/years, and (2) the magnitude and dynamics of seasonal and intra-annual groundwater level fluctuations have significantly changed since 1950.

The S.S. Papadopulos & Associates (2012) modeling study and the ongoing UC Davis groundwater study rely on a survey of geology and groundwater features of the Scott Valley conducted by the USGS in 1958 (Mack, 1958). The report describes in detail the geologic features in the basin and points out some interesting features of the groundwater system. Most of the wells in the area are shallow dug wells, averaging about 25 feet. Recharge to groundwater comes in the form of rainfall, seepage from tributary streams, and irrigation. Losses from groundwater come mainly in the form of evapotranspiration and hyporheic flow into the Scott River. Mack estimated the storage capacity in the flood-plain sediments to be about 220,000 acre-feet. As part of the Mack (1958) study, a number of groundwater level measurements were made either from existing or installed monitoring wells. A number of these wells continued to be used as monitoring wells. These data serve as a primary data source for subsequent Scott Valley groundwater modeling studies, including the current study presented in this chapter.

### 3.4.2 Approach – Upper Klamath Basin

Groundwater in the Upper Klamath Basin is being simulated using the USGS MODFLOW finite-difference model developed by Gannett et al. (2012). Details of the model configuration may be found in the mentioned study; however, a general discussion is included here. Emphasis in this discussion is placed on two elements of the model with direct linkages to the surface water hydrologic model developed over the region (VIC). The approach discussed below helps to provide context for the approach of evaluating the impacts of projected climate.

The MODFLOW model developed for the Upper Klamath Basin has 100,070 active cells and a historical simulation period of water years 1970 through 2004 (October 1969–September 2004). For the purposes of this study, and to maintain consistency with datasets used to evaluate surface water supply, the historical period was modified to water years 1970 to 1999. The model has quarterly stress periods (every 3 months) and each stress period is divided into five equal timesteps. Model input data are developed on a quarterly basis (i.e., disaggregation to individual timesteps occurs internally within the model).

The MODFLOW model utilizes a number of packages that help to improve its representation of physical processes. The packages implemented in this configuration include the recharge package, well package, stream package, general head boundary package, evapotranspiration package, drain package, and reservoir package, in addition to the basic package. There are two primary linkages with surface water inputs, such as outputs from the VIC surface water hydrologic model. First, VIC model precipitation inputs are used to develop seasonal relationships between precipitation and recharge, which are later used to develop scenarios of future recharge based on projected precipitation. Second, VIC simulated potential evapotranspiration (PET) and actual ET are used to compute the upper threshold for ET used by the MODFLOW model (computed as the difference between PET and actual ET). The modeling study conducted by

Gannett et al. (2012) relied on surface water inputs from the USGS Precipitation Runoff Modeling System (PRMS), developed over the same region.

Assessment of historical groundwater levels in the Upper Klamath Basin primarily comes from the modeling efforts by Gannett et al. (2012). However, as part of the assessment of groundwater supplies, the MODFLOW model was rerun over the modified historical period and is the baseline for comparison of projected groundwater levels.

### 3.4.3 Present Availability and Historical Trends – Upper Klamath Basin

Present availability and historical trends in groundwater elevation and recharge are discussed in the context of previously completed work by Gannet et al. (2012). The historical MODFLOW simulation described by Gannett et al. (2012) was used as the historical baseline for the assessment of groundwater in the Upper Klamath Basin for this water supply assessment.

Historical availability of groundwater is presented in this section with respect to recharge and groundwater elevations. Historical recharge to the groundwater system was developed by Gannett et al. (2012) using summed subsurface flow (interflow) and groundwater flow terms from the PRMS model. Subsurface (interflow) generated by PRMS represents shallow rapid subsurface flow, which is not well simulated by MODFLOW. Therefore, adjustment factors were applied to the summed recharge values to more accurately simulate recharge in the basin. The resulting historical recharge used as input to the MODFLOW model is illustrated by Figure 3-10.

The highest recharge, according to Figure 3-10, is along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains. The lowest recharge amounts are in the central and southern parts of the basin. It should be noted that amount of recharge does not necessarily correspond to areas with highest ground permeability. Discussions from Section “Upper Klamath Groundwater Basin”, addressing groundwater characteristics of the basin, indicate that the western part of the basin is generally characterized by low permeability, while parts of the central basin are characterized as having high permeability and high groundwater yield. Greater recharge occurs along the western boundary primarily due to the fact that there is more water available for recharge, compared with the central portion of the basin.

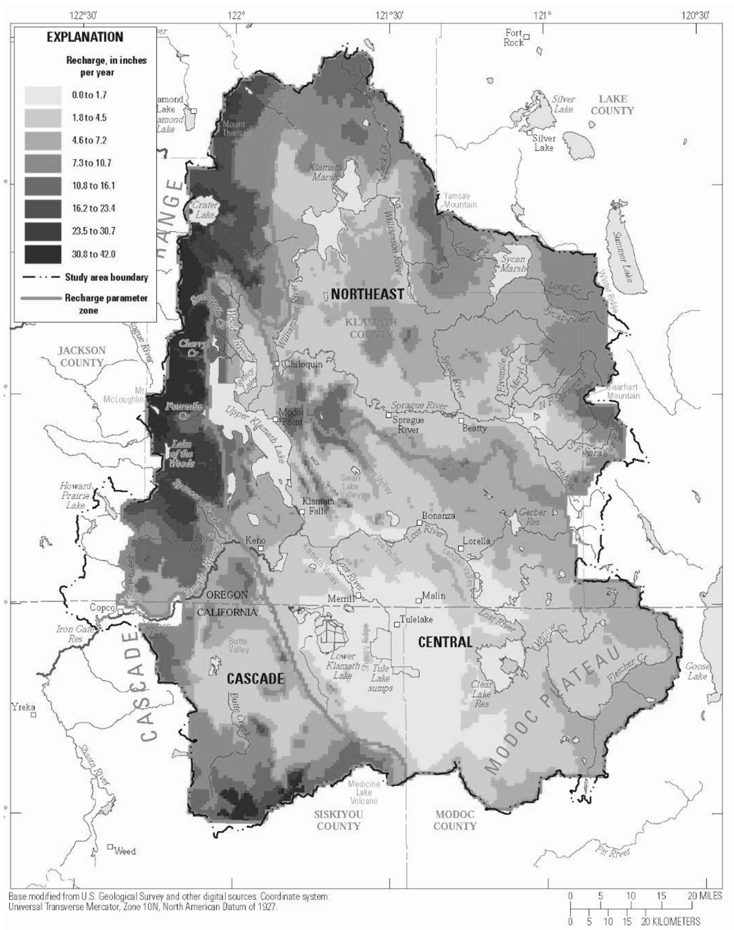



**Figure 7.** Estimated mean annual groundwater recharge from precipitation in the upper Klamath Basin, Oregon and California, 1970–2004, in inches, and recharge parameter zones.

*Source: Figure 7 from Gannet et al., 2012*

Note: Recharge Zone 1 (Cascade) lies along the western boundary of the basin. Recharge Zone 2 (Northeast) covers the northeastern part of the basin. Recharge Zone 3 (Central) covers the central and southeastern part of the basin.

**Figure 3-10. Summary of mean annual recharge over the Upper Klamath River Basin**

Gannett et al. (2012) also summarizes historical simulated groundwater elevations, compared with observations, for a number of sites throughout the Upper Klamath Basin model domain. We provide a sample of figures for two sites, including the Wood River sub-basin, located upstream of Upper Klamath

Lake (Figure 3-11) and the Lower Klamath Lake sub-basin, located in the southcentral portion of the model domain (Figure 3-12).

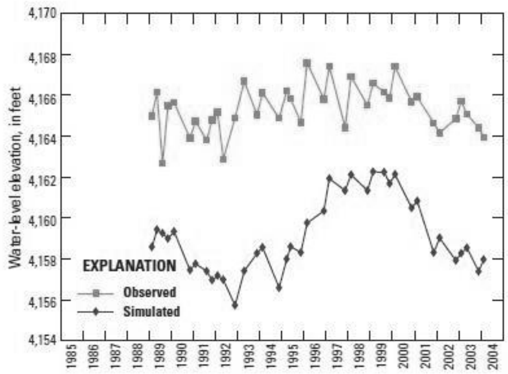



**Figure 18.** Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

*Source: Figure 18 from Gannett et al., 2012*

**Figure 3-11. Observed and simulated water-level elevations in the Wood River sub-basin**

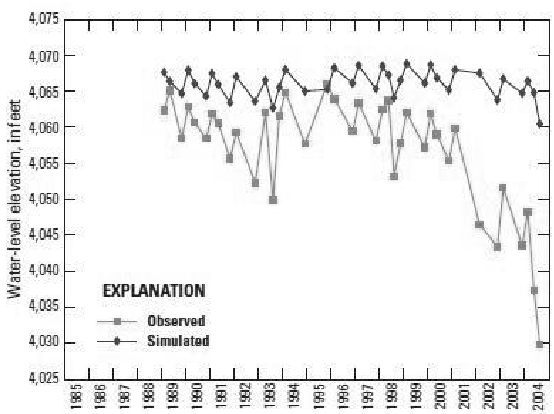



**Figure 36.** Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

*Source: Figure 36 from Gannett et al., 2012*

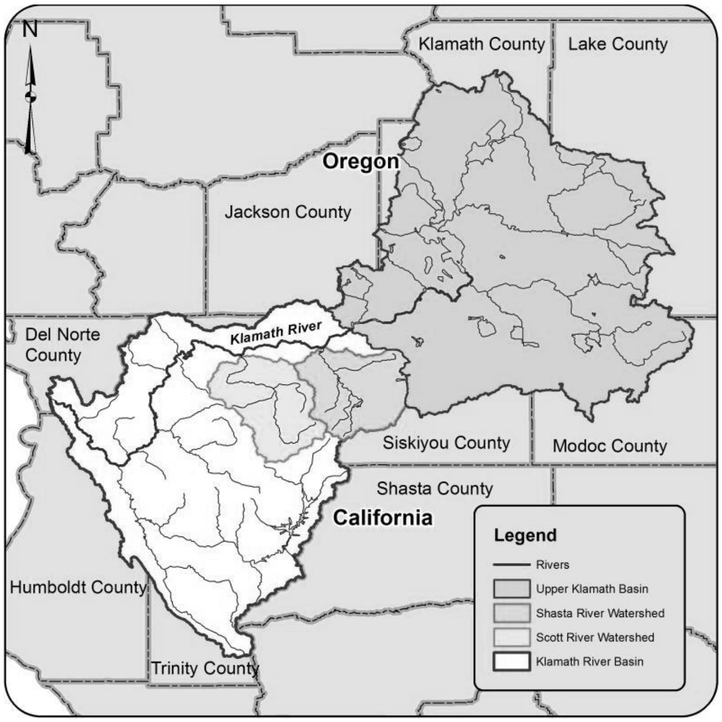
**Figure 3-12. Observed and simulated water-level elevations in the Lower Klamath Lake sub-basin**

Results for these two sites are representative of the types of calibration results for the MODFLOW model. In general, the model captures the low frequency variability in groundwater levels over the period from the late 1980s through 2004. The model is also able to capture much of the year-to-year variability in groundwater levels. The difference between simulated and observed groundwater elevations can vary from on the order of 5 feet to 30 feet, depending on the site and year. Gannett et al. (2012) suggest the larger differences (seen in parts of the Wood River sub-basin as shown on Figure 3-11, for example) may be due to the coarse vertical discretization of the model, relative to the gradients of groundwater flow. Also for the Lower Klamath sub-basin site (Figure 3-12), the model is not able to capture the decline in observed groundwater elevation that occurs after about 2000 (corresponding with drought and increases in pumping). Differences between observed and simulated groundwater elevations may be attributed, at least in part, to lack of accurate information on rates and locations of pumping in some parts of this sub-basin (Gannett et al., 2012).

> **Historical Groundwater Availability – Upper Klamath Basin**
>
> The highest recharge to groundwater occurs along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains, while the lowest recharge amounts are in the central and southern parts of the basin.

### 3.4.4 Approach – Scott and Shasta Valleys

The groundwater portion of the Klamath River Basin Study water supply assessment consists of analysis for three main regions within the Klamath River Basin: the Upper Klamath Basin, the Scott Valley, and the Shasta Valley (see Figure 3-13). These regions represent the majority of groundwater use in the Klamath River Basin, as inferred from defined groundwater regions from California's Groundwater Bulletin 118 (CDWR, 2003). To the extent possible, these analyses rely on existing modeling tools and data.




*Sources: Principal Aquifers, http://www.nationalatlas.gov/mld/aquifrp.html; Scott and Shasta Valley Well Data, http://www.water.ca.gov/waterdatalibrary/groundwater/index.cfm.*

**Figure 3-13. Map of modeled groundwater basins within the Klamath River Basin**

Existing groundwater modeling tools for the Scott and Shasta Valleys were explored in the preparation of this water supply assessment. No existing groundwater modeling tools were identified for the Shasta Valley, although there are ongoing studies at the University of California at Davis related to groundwater dynamics of the Shasta Valley.[3] There is also an existing draft groundwater data needs assessment developed by CDWR which has not been finalized (CDWR, 2011). The existing groundwater model for the Scott Valley, developed by S.S. Papadopulos & Associates, Inc. (2012) for the Karuk Tribe, was explored for possible use in the Klamath River Basin Study. However, use of this modeling tool was deemed infeasible due to the reasons outlined below:

[3] http://hsgg.ucdavis.edu/research/student-abstracts/

1. The modeling tool was not readily available for use by Reclamation. In other words, additional funding would have been required to either contract with S.S. Papadopulos & Associates, Inc. to participate in the study or fund them to package the model for use by Reclamation staff.
2. The model was designed with a relatively narrow focus on the impact of groundwater pumping on streamflows.
3. Confidence in the results from a sophisticated MODFLOW finite-difference groundwater model for the Scott Valley, where input data are limited, was not high enough to justify the cost of its implementation in the study.
4. The spatial resolution of the surface water hydrologic model that provides surface water inputs to the groundwater model is coarse in comparison with the size of the Scott River Basin, which also limits confidence in the utility of applying a sophisticated MODFLOW model in the basin.

Conceptual regression-based groundwater screening tools were developed for both the Scott and Shasta Valleys based on the approach taken by Reclamation (2013) in the Santa Ana Watershed Basin Study. The added advantage of developing these tools is consistency in the approach for the two neighboring watersheds. This section briefly describes the groundwater screening tool as it was applied in this Klamath River Basin Study. Details regarding data used as input to the Scott and Shasta Valley tools are described in Appendix B, Supplemental Information for Assessment of Water Supply.

The regression-based groundwater model relies on historical inflows and outflows from the groundwater system, estimated from available data, including spatially distributed recharge from precipitation, focused recharge from stream and canal seepage losses or deep percolation of irrigation water, groundwater abstraction by pumping, and other inflows and outflows. The model is calibrated and verified with respect to available observations. The model may then be applied using projected future conditions, as well as applied management alternatives, to evaluate the effects of climate change and adaptation strategies on groundwater resources.

The groundwater screening tool estimates fluctuations in basin-scale groundwater levels in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports, if applicable. The tool allows users to quickly estimate basin-scale groundwater conditions under a broad range of future scenarios and provides insight into the primary factors driving basin-scale groundwater fluctuations.

This screening tool is based on a conceptual model which considers fluctuations in basin-average groundwater elevations as a function of basin-scale drivers.

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These drivers are illustrated in Figure 3-14 and may be categorized by the following: water availability (precipitation, local streamflow, and trans-basin imports), water demand (municipal and industrial demand, agricultural land use, and evaporative demand), and an optional exogenous input that represents groundwater management objectives that affect basin-scale groundwater levels. As a result, use of the groundwater screening tool does not require detailed information regarding local hydrologic, geologic, climatic, and anthropogenic factors that may affect local groundwater fluctuations. However, it should be noted that as a result of this basin-scale approach, the groundwater screening tool is primarily applicable at the scale of individual groundwater basins or sub-basins, where the effects of local-scale conditions are largely averaged out and where subsurface inflows and outflows from surrounding areas are negligible.

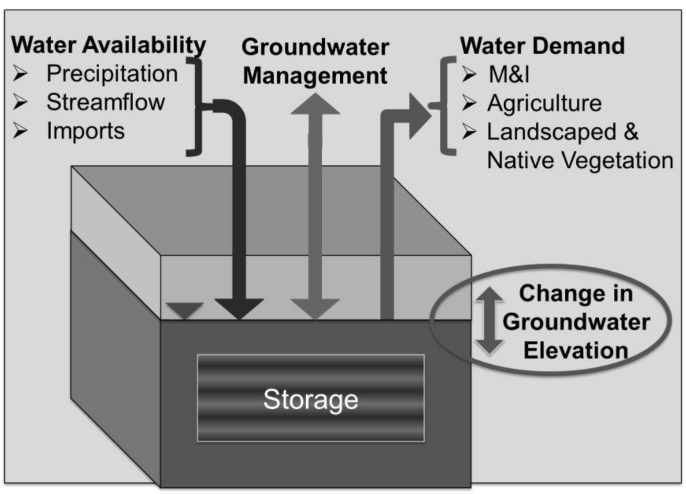
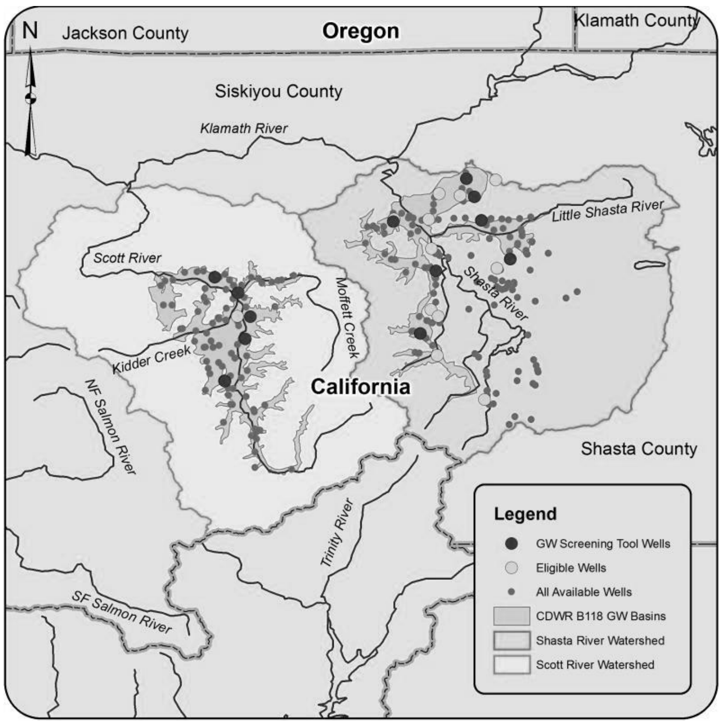



**Figure 3-14. Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool**

The model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR's Bulletin 118 (CDWR, 2003). CDWR Bulletin 118 was first created in the 1950s as a means for collection and evaluation of groundwater data throughout California. Bulletin 118 has been updated numerous times, with the latest update in 2003. Bulletin 118 has defined groundwater basins, including one each for the Scott and Shasta Valleys. Scott and Shasta Valley groundwater basins roughly correspond with the unconsolidated sand and gravel PNW Basin-fill aquifers from the USGS (2003) National Atlas of Principal Groundwater Aquifers[4] map. The Bulletin 118

[4] http://www.nationalatlas.gov/wallmaps.html#aquifers

groundwater basins define the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in Figure 3-15.




Note: The map shows all available wells (grey), eligible wells3 (pink), and wells[3] used in development of the groundwater screening tools for both watersheds (red).

**Figure 3-15. Map of CDWR Bulletin 118 groundwater basins for the Scott and Shasta River basins**

Historical data were used to determine regression coefficients and to evaluate model performance over the historical period (1980–1999). For this study, historical groundwater elevation data averaged over each groundwater basin were used to fit the regression models. These data came from CDWR and USGS data archives. Monthly mean groundwater elevations were calculated from the available instantaneous measurements. Note that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly time series were computed from these measurements. Well data were screened for individual outliers and analyzed to determine whether the groundwater elevations at the well are representative of the

average behavior of each groundwater basin (Scott and Shasta). Steps were taken to avoid potential biases due to variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. Additional details are provided in Appendix B, Supplemental Information for Assessment of Water Supply, regarding the sources of well data, methods for screening the data, and methods to account for potential biases in well records. Inputs of precipitation, evaporative demand, and streamflow were computed based on VIC model simulations, aggregated to a monthly timestep and averaged over each groundwater basin. Demands such as agricultural and municipal, domestic, and industrial demand were developed based on available data described in detail in Appendix B, Supplemental Information for Assessment of Water Supply. Note that aquifers outside of CDWR Bulletin 118 and well data not archived by CDWR or USGS were not considered as part of this modeling study, which may present limitations in the applicability of the modeling tools to simulate basin-wide behavior.

### 3.4.5 Present Availability and Historical Trends – Scott and Shasta Valleys

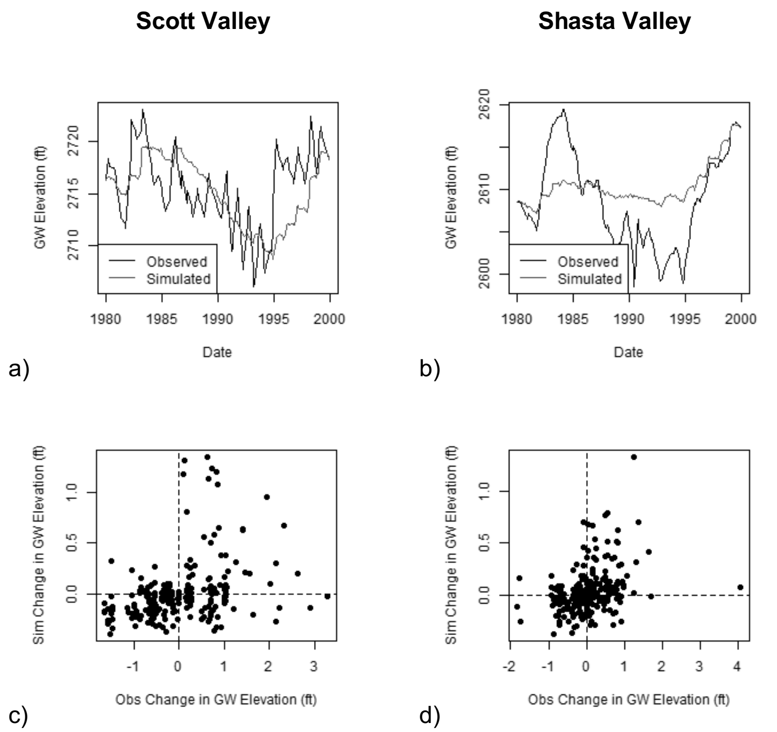
The groundwater screening tool was applied to the groundwater basins in the Scott and Shasta watersheds that were defined by CDWR Bulletin 118 (CDWR, 2003) and are shown on Figure 3-15. There is one defined groundwater basin for each of the watersheds. The screening tools were fit using a linear regression model to the collected observed data (see Equation 1 in Appendix B, Supplemental Information for Assessment of Water Supply). The models were then verified by exploring variations of the groundwater elevation input data. The regressions were tested to ensure that well data used most closely represented basin-wide behavior. Correlations of observed groundwater elevation with individual model inputs were explored and statistically significant correlations (at the 95th percentile confidence level) were found between observed groundwater elevation, precipitation, and runoff for some wells (but not all), indicating that groundwater levels in the Scott and Shasta Valley CDWR Bulletin 118 aquifers are related to climatic fluctuations.

> **Historical Groundwater Availability – Scott and Shasta Valleys**
>
> The statistical groundwater screening tools may be applicable for evaluating the relative impacts of climate change amounts in the central and southern parts of the basin.

Figures 3-16 (a) and (b) illustrate observed and simulated basin-averaged groundwater elevation for the Scott and Shasta groundwater basins, respectively, for the period 1980–1999. The figures show that the groundwater screening tools capture the larger frequency fluctuations (i.e., multi-year trends) in groundwater

elevation, but are not able to resolve finer interannual fluctuations. Both groundwater basins experienced declines in groundwater elevation during the late 1980s and early 1990s on the order of about 20 feet, corresponding with lower precipitation and streamflow during that period. Observed groundwater elevations in the Scott Valley have ranged between about 2,705 feet and 2,725 feet, while observed groundwater elevations in the Shasta Valley have ranged between about 2,600 feet and 2,620 feet. Interannual fluctuations may be driven by local-scale non-linear processes that are not represented in the basin-scale screening tool, or by management activities (for example, pumping) that are not included in this analysis.

Figures 3-16 (c) and (d) illustrate observed change in groundwater elevation versus simulated change in groundwater elevation. They graphically show the data points on which the linear regressions for the groundwater screening tools are based. Model fit statistics summarized in Table 3-4 show that for both the Scott and Shasta Valleys, the screening tools are able to explain a little more than 10 percent of the variance in the data (coefficient of determination, or $R^2$, of 0.11 and 0.12, respectively, for Scott and Shasta groundwater basins). A more robust model would have higher $R^2$ values. The degree of model fit indicates that the tool may be applicable for evaluating the relative impacts of climate change, but is not applicable for evaluation of short-term management decisions. In the future, additional and improved data sources may help to improve model fit and thereby the applicability of the tool for a range of purposes.




Note: (a) groundwater elevation for the Scott groundwater basin; (b) groundwater elevation for the Shasta groundwater basin; (c) groundwater elevation change for the Scott groundwater basin; (d) groundwater elevation change for the Shasta groundwater basin

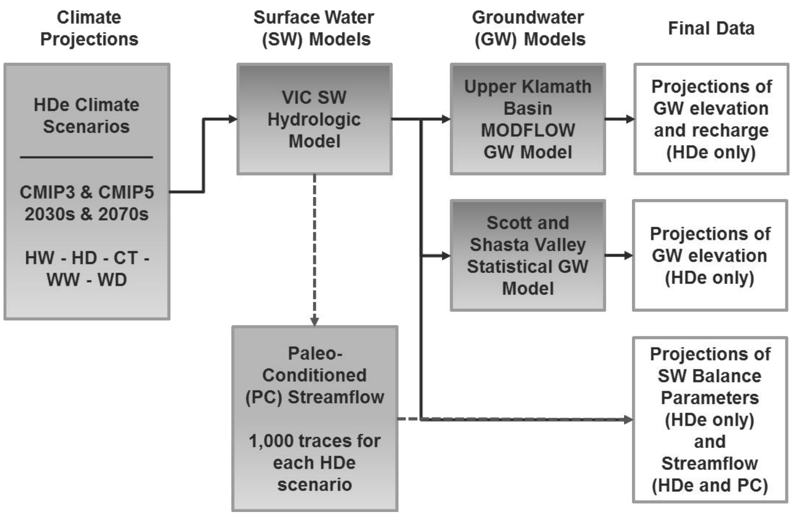
**Figure 3-16. Simulated and observed Scott and Shasta basin groundwater elevations, as well as simulated and observed changes in groundwater elevations**

**Table 3-4. Summary of model fit for Scott and Shasta groundwater basin screening tools**

| Statistic | Scott Groundwater Basin | Shasta Groundwater Basin |
|---|---|---|
| **Multiple R2** | 0.11 | 0.12 |
| **Adjusted R** | 0.33 | 0.35 |
| **P-value** | 0.0000511 | 0.0000101 |
| **Residual Standard Error** | 0.838 | 0.5905 |

## 3.5 Effects of Climate Variability and Change on Supply

This section builds upon tools developed for assessment of historical supplies and provides a detailed discussion of the approach for developing and utilizing future climate scenarios to evaluate projected changes in surface and groundwater. A diagram illustrating the overall approach for evaluating the effects of climate change on water supply is provided in Figure 3-17. Details regarding data linkages between steps are provided in the next section.




Note: HDe refers to ensemble hybrid delta climate scenarios; PC refers to paleo-condition streamflow projections.

**Figure 3-17. Summary of approach for evaluating the effects of climate change on surface water and groundwater supplies**

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020 through 2049) and 2070s (represented by the mean from 2060 through 2089). In evaluating the effects of climate change on water supply, projections of future supply are commonly compared with that of a historical reference period. The historical reference period for the Klamath River Basin Study is 1970–1999. It should be noted that historical climate has not changed steadily through the 20th century. Basin average temperature has increased from the 1970s through the rest of the century, following an approximate 40-year period of relatively steady temperatures. Basin annual precipitation has fluctuated considerably during the past century, but was relatively steady from the 1940s

through the rest of the century (Reclamation, 2011c). Figure 3-7 illustrates historical trends from 1950 through 1999.

### 3.5.1 Approach

As a step toward greater understanding of the implications of climate change on the Klamath River Basin, this section first describes the approach for development of climate scenarios for the Klamath River Basin Study water supply assessment, followed by discussions of approaches for evaluation of climate change impacts on surface and groundwater supplies. With respect to surface water, the assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture, and low streamflow periods that have major implications for fish and wildlife and the livelihoods of basin residents. With respect to groundwater, the assessment focuses on projected changes in groundwater recharge and discharge, as well as overall changes in groundwater elevations.

#### *3.5.1.1 Climate Projections*

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales (for example, the PDO). Changes in climate due to natural variability will continue to occur in the future, along with changes due to increased greenhouse gas concentrations from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

Climate Projections

The Klamath River Basin Study utilizes climate projections from World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5).

The state of practice for evaluation of the long-term availability of water supply is to incorporate a range of approaches to characterize past and projected climate. The approaches may include use of paleo-conditioned climate data and use of projections from general circulation models (GCMs). Paleo-conditioned climate data are developed from long-term climatic records (such as tree rings, pollen, etc.) that have been used to capture the natural variability of climate over thousands of years.

Another approach involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impact studies. This can be done using dynamical downscaling, which uses GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which uses historical data as a way of statistically mapping GCM scale information to a finer resolution. Statistical downscaling may involve delta method experiments, which compute period change values based on GCMs and apply them as perturbation factors to historical data. Numerous variations exist within these three categories and there are also approaches that are hybrids of these categories.

The Klamath River Basin Study relies on data and modeling from Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 western states that fall within Reclamation's management domain. These projections are based on simulations from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3; Meehl et al., 2007), which are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). Projections based on Phase 5 of the same model intercomparison project (CMIP5) reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and greenhouse gas emissions. These simulations, which were made available in 2011, are summarized in IPCC's Fifth Assessment Report (Taylor et al., 2012). Both sets of projections, CMIP3 and CMIP5, are utilized as part of the Klamath River Basin Study water supply assessment.

Details regarding the approach for use of climate projections and development of climate scenarios for the Klamath River Basin Study are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, Figure 3-18 illustrates the overall approach for downscaling GCM projections to a finer spatial scale. The figure shows that a similar approach is taken regardless of the choice of CMIP3 or CMIP5 simulations: namely, emissions scenarios are incorporated into GCM simulations. These simulations are bias corrected at the resolution of the GCM and then statistically downscaled to the resolution of the Klamath River Basin Study hydrology models. Bias correction allows for the removal of systematic biases from GCM simulations, based on historical regional climate datasets derived from observations.

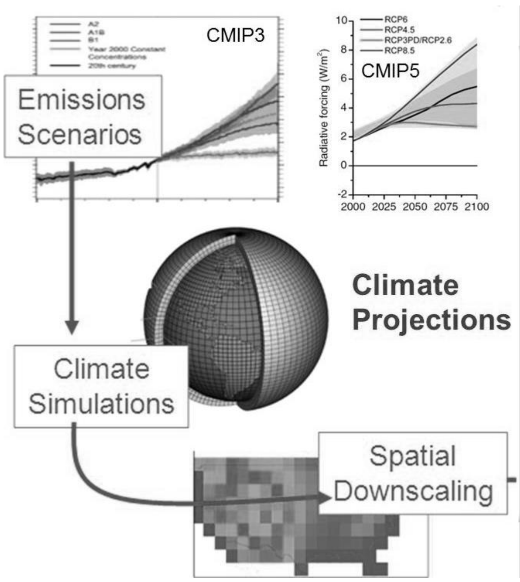



**Figure 3-18. Downscaling elements**

#### *3.5.1.2 Deriving Climate Change Scenarios from Climate Projections*

The high number of climate projections from CMIP3 and CMIP5 (on the order of hundreds of realizations) make their direct use in long term planning studies cost prohibitive in many cases. The Klamath River Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes the available suite of climate projections to derive a smaller number of climate change scenarios to inform long term planning.

The Klamath River Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d). The scenarios are developed based on both CMIP3 and CMIP5 statistically downscaled GCM projections, as these are considered equally likely potential climate futures at this time. Details regarding the approach for deriving climate scenarios from CMIP3 and CMIP5 climate projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, a brief overview is provided below.

The hybrid delta method approach for developing climate scenarios involves perturbing historical climate (precipitation and temperature) by change factors computed as the change in precipitation and temperature by month between a chosen future planning horizon and a baseline historical period (Reclamation, 2010). Change factors may be developed for each available downscaled climate projection (CMIP3 or CMIP5) or may be developed based on ensembles of climate projections. The Klamath River Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

## HDe Climate Scenarios

Ensemble hybrid delta climate scenarios representing five quadrants of precipitation and temperature change (warm wet, warm dry, central tendency, hot dry, hot wet) are used to encompass a range of possible climate futures for two future time horizons, the 2030s and the 2070s.

The HDe method involves defining a climate change scenario based on pooled information from a collection of climate projections. Use of a sufficiently large number of projections (commonly called an ensemble) pooled together reduces the signal of internal climate variability (which is inherent in each single projection), which may be misinterpreted as climate change. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios. These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

Historical precipitation and temperature are mapped, using a quantile mapping technique, onto the bias corrected GCM data to produce a set of transformed observations reflecting future conditions. The entire observed time series of temperature and precipitation at each hydrologic model grid cell is perturbed in this manner, resulting in a new time series that has the statistics of the bias corrected GCM data for the future period, but preserves the time series and spatial characteristics of the gridded temperature and precipitation observations.

The HDe scenarios for the Klamath River Basin Study culminate in a total of 20 scenarios, including two future time horizons (2030s and 2070s), five quadrants of projected change (HW, HD, CT, WW, and WD), and two sets of projections (CMIP3 and CMIP5). Each of these scenarios resemble the historical inputs of daily precipitation and temperature (minimum and maximum) to the VIC surface water hydrologic model in format and period of record because they are all perturbations of historical time series. Windspeed, the remaining required input to the VIC model, was assumed not to change between historical and future time periods. This assumption is in part due to the coarse resolution of historical windspeed data used in the Maurer et al. (2002) historical meteorological dataset

and the associated high level of uncertainty in the data. However, to provide some context, Pryor et al. (2012) found some evidence of lower intense windspeeds in the western U.S. for the 2041–2062 period compared with 1979–2000 from regional climate model simulations.

Figure 3-19 summarizes projected changes in precipitation (a) and temperature (b) by month according to the five HDe climate scenarios for each time period in relation to the full suite of CMIP3 and CMIP5 projections by month. This figure illustrates that the derived climate scenarios generally span the range of projected future precipitation and temperature by the greater number of climate projections. However, with respect to precipitation change, it appears the HDe scenarios project a greater tendency toward increased precipitation during summer months (August, in particular) than the raw climate projections indicate. This is likely due to the fact that the HDe projections are based on projected annual changes in precipitation, not seasonal or monthly changes. Projected annual changes in precipitation appear to be influenced more by increases in winter precipitation.

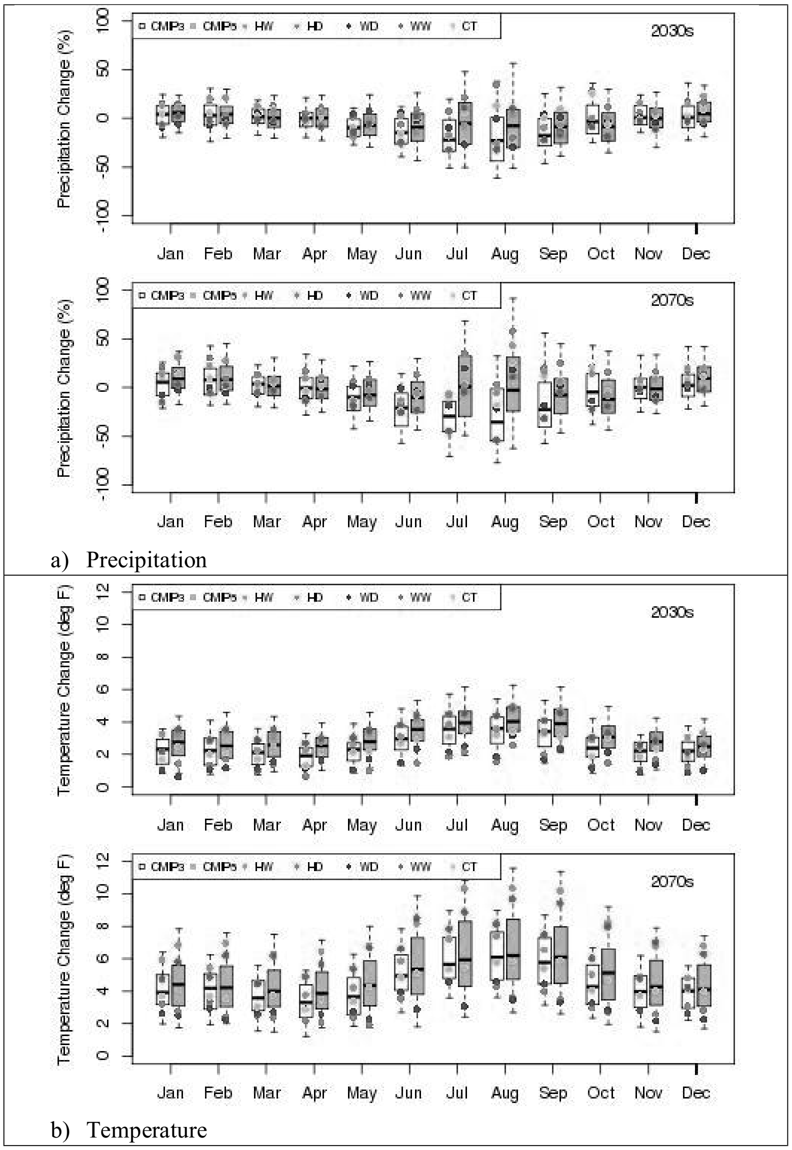



**Figure 3-19. Changes in mean monthly precipitation and temperature**

HDe scenarios have a number of distinguishing features, with associated strengths and weaknesses. One weakness of this approach is that analysis of climate change impacts is limited to the future time horizons chosen when developing precipitation and temperature change factors. Another weakness is that the scenarios do not incorporate projected changes in drought variability or sequencing of storm events. One key strength of the HDe approach is that the time sequence of projected future storm events matches historical climate data, facilitating direct comparison between the observations and future scenarios. The HDe approach is suitable for water resources planning at both daily and longer time scales, supports analysis of daily hydrologic extremes such as flood and drought intensity, and provides consistency across a range of spatial scales (Hamlet et al., 2010).

#### *3.5.1.3 Deriving Paleo-Conditioned Streamflow Projections*

Understanding drought variability is critical to managing water resources across the western U.S. The HDe scenarios described in the previous section may be used as input to surface and groundwater hydrologic models to evaluate changes in the water balance. As mentioned, HDe scenarios are perturbations of the historical record that reflect the statistics of future climate over some chosen time period. As a result, they do not explore the possibility of changes in drought variability (i.e., length or severity of drought periods and wet periods).

Paleo-climate information derived from tree rings or other proxies provides a greater context for sequencing and duration of wet and dry periods than the historical record can provide, often going back hundreds of years. The paleo-conditioned streamflow projections described in this section achieve a blend of projected climate information derived from GCMs and paleo-climate information.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time PDSI (Palmer Drought Severity Index) using tree-ring chronologies. This extended PDSI record for North America is available as a gridded (2.5 degrees latitude by 2.5 degrees longitude) timeseries, nearly 200 miles on a side, that dates back nearly 2000 years in some locations. Availability of this extended gridded PDSI record provides an opportunity to analyze regional drought and wet spell characteristics.

For the Klamath River Basin Study water supply assessment, a representative grid location (see Figure 3-20) from the extended gridded PDSI archive was used to analyze long-term wet and dry spells in the Klamath River Basin. Adjacent grid locations provided similar results. The specific location of the PDSI grid used has a center with latitude 42.5 degrees N and longitude 120.0 degrees W., shown by a green triangle in Figure 3-20. The PDSI time-series used from this grid extended from 1400 through 1999.

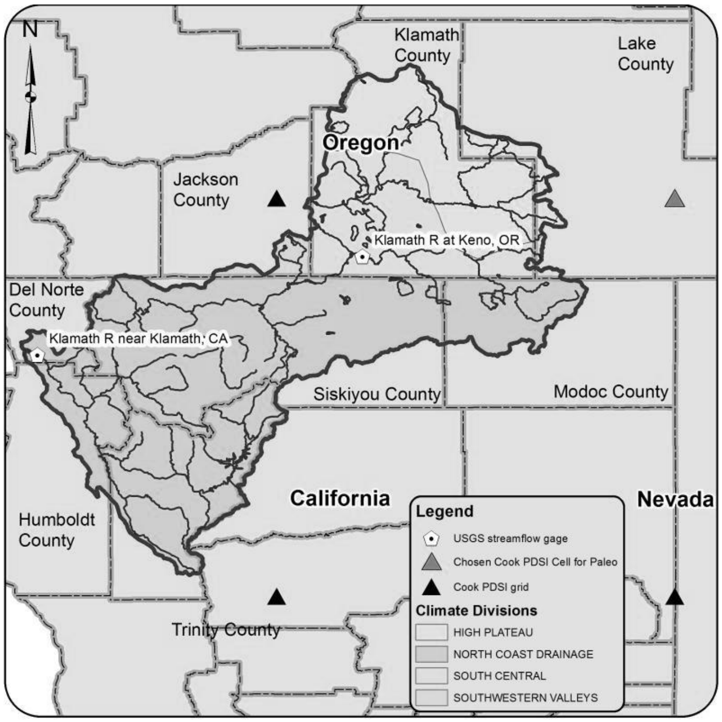



**Figure 3-20. Overview map of the Klamath River Basin with Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA and at Keno, OR**

To understand the time-varying nature of wet and dry spells, the PDSI index can be used to determine the probability of regional hydrology shifting from one state to another. In this study, the Klamath River Basin was defined to be either in dry state when the summer time PDSI value in a given year was less than 0 (negative PDSI corresponds to dry conditions), or in a wet state when PDSI was greater than 0 (positive PDSI values correspond to wet conditions). Based on the defined states, probabilities may be derived for the likelihood of transitioning from one state to another. Flow magnitudes can be assigned based on the probabilities, which allows for evaluation of historical streamflow over the instrumental record and projected streamflow compared with the paleo period.

The results for the Klamath River indicate that paleo-conditioned historical simulations show reduced lengths and volumes of wet periods. Results also show droughts of reduced length and deficit, demonstrating that just changing the ordering of flows over the historical period results in periods of both reduced droughts and surpluses. Furthermore, the wet period volumes could be quite a bit lower than what has been historically available, according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than is shown in the recent instrumental record.

## Paleo-Conditioned Streamflow Projections

Wet period volumes could be quite a bit lower than what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than what is shown in the recent instrumental record.

Paleo-conditioned streamflow projections are not carried throughout the Klamath River Basin Study water supply assessment and subsequent phases of the Basin Study for two primary reasons. First, analysis of paleo-conditioned streamflow, including historical and HDe scenarios, suggests that periods of drought and surplus over the paleo record are within the range of variability experienced for the historical 1950–1999 period. Thus, including paleo-conditioned projections of streamflow, and potentially other variables, would be computationally time-intensive yet would not yield additional information. Second, because the Klamath River Basin lacks an integrated surface water – groundwater model, there would be inconsistencies in data linkages between models that make use of paleo-conditioned projections infeasible. For example, the groundwater models rely on inputs of climate, recharge, and streamflow, yet paleo-conditioned projections of climate and water balance variables do not exist to correspond with the paleo-conditioned streamflow projections. Paleo-conditioned streamflow projections may provide a greater context for future water supply projections, but are not directly used in further analysis.

### *3.5.1.4 Surface Water Hydrology*

Assessment of climate change impacts on surface water supply was conducted using HDe (ensemble informed hybrid delta) scenarios and was informed by paleo-conditioned streamflow projections. The overall approach is described below and is illustrated in an overview diagram in Figure 3-21.

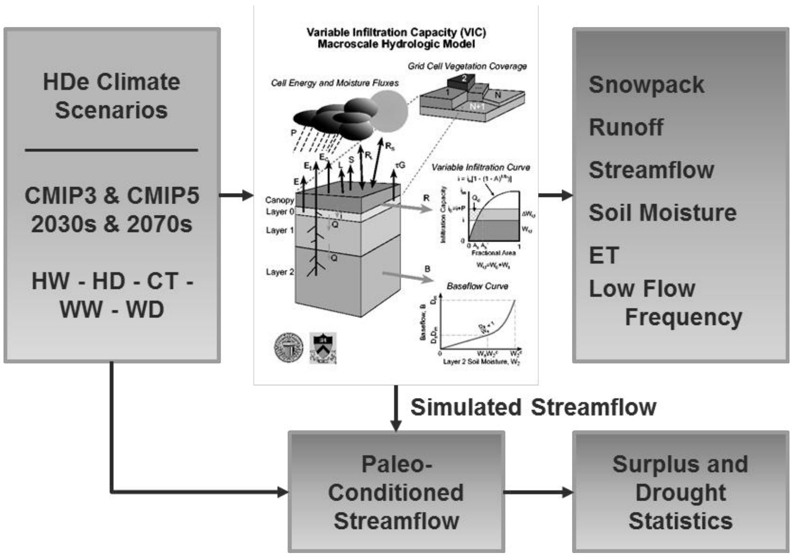



**Figure 3-21. Approach for assessment of projected surface water supplies**

HDe scenarios may be directly used by the VIC model to generate associated projections of snowpack, runoff, and other elements of the water balance. In evaluating the implications of climate change, the water supply assessment first provides comparisons of results based on CMIP3 and CMIP5 projections with respect to mean annual precipitation and temperature, April 1 SWE, and mean annual runoff.

Following the comparison of CMIP3 and CMIP5 results, the assessment discusses projected changes in seasonal precipitation and temperature, snowpack on April 1, mean annual runoff, spring runoff, June 1 soil moisture, mean annual ET, mean monthly streamflow at select sites, annual runoff timing, and changes in the 7 day low flow with 10 year recurrence interval (also called 7Q10). This part of the assessment focuses on results using CMIP5 projections (unless otherwise noted) for the two future time horizons (2030s and 2070s); however, figures based on CMIP3 projections, corresponding to those presented in the water supply assessment, are presented and briefly discussed in Appendix B, Supplemental Information for Assessment of Water Supply.

Drought and surplus statistics are evaluated based on the developed paleo-conditioned streamflow traces. Paleo-conditioned streamflow relies on projected natural streamflow output from the VIC model as well as statistics developed from the analysis of the paleo-record. Projected natural streamflows from the VIC model are resampled 1,000 times for each of the five HDe climate change scenarios, future time horizons, and projection types (CMIP3 and CMIP5) to develop statistics of projected surplus and drought volumes and lengths.

#### *3.5.1.5 Groundwater Hydrology*

This section describes the approaches for utilizing climate change scenarios to evaluate projected changes in groundwater recharge, discharge, and elevations in three groundwater basins of the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys.

**Upper Klamath Basin**

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing MODFLOW finite-difference groundwater model developed by Gannett et al. (2012). For this study, the model was driven by HDe climate scenarios and surface water hydrologic projections, and results were compared with the historical simulation (presented and summarized in Section 3.4.3, Present Availability and Historical Trends – Upper Klamath Basin) to evaluate results due to changes in climate alone, excluding any impact due to changes in groundwater demand (i.e., pumping). Paleo-conditioned streamflow projections were not taken through the Upper Klamath Basin groundwater impacts analysis because stream stages are held constant in the MODFLOW simulations and Gannett et al. (2012) determined that streams generally have very little net exchange with the groundwater system. The avenues for incorporation of projected surface water inputs into the MODFLOW model are listed below, and they do not have associated paleo-conditioned projections.

1. Projected maximum ET for each of the five HDe climate change scenarios, where maximum ET is represented as PET less actual ET as computed from VIC surface water hydrology model output
2. Projected groundwater recharge for each of three recharge zones for each of the five HDe climate change scenarios

The methodology for developing each type of projected MODFLOW input is described briefly below and illustrated in an overview diagram in Figure 3-22.

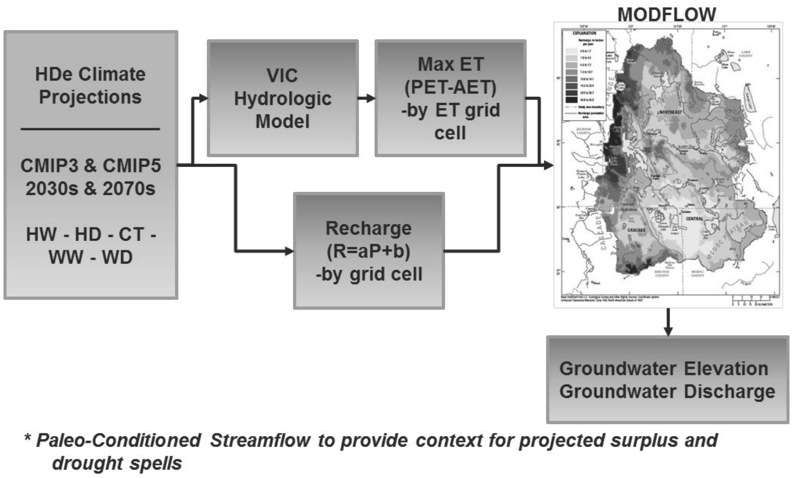



**Figure 3-22. Approach for assessment of projected groundwater supplies in the Upper Klamath Basin**

*Maximum Evapotranspiration Rate*

Evapotranspiration is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or evapotranspiration package. One of the principal input parameters is the maximum ET rate associated with groundwater. Gannett et al. (2012) computed this parameter based on output from the PRMS surface water hydrology model. Specifically, this parameter is computed as the difference between PET and actual ET. This difference represents the amount of potential demand that could be supplied by groundwater and is not supplied by precipitation.

In this study, the VIC model was used to generate meteorological inputs for future MODFLOW simulations. The VIC model was chosen, as opposed to PRMS, because it is available for the entire Klamath River Basin, is widely used for studies of climate change impacts, and was used in the hydrologic modeling and development of hydrologic projections as part of Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). Maximum ET was computed on a quarterly (seasonal) basis from VIC simulations for the five HDe climate change scenarios. Quarterly maximum ET computed from VIC simulations (at 1/8th degree spatial resolution) was compared with historical maximum ET used in the historical MODFLOW simulation, aggregated to VIC's spatial resolution. Quarterly (stress period) change factors were developed at the VIC model spatial resolution and factors were applied to historical maximum ET from MODFLOW for each MODFLOW cell within a VIC grid cell. The reason for using change factors and not directly applying projected maximum ET from the VIC model is

to avoid introducing bias due to the differing model constructs (i.e., PRMS generated historical maximum ET while VIC generated projected maximum ET).

*Groundwater Recharge*
The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model. Because the VIC model was used to generate inputs for future projection simulations, and because historical simulated recharge from VIC may be quite different from recharge used in the historical MODFLOW simulation (derived from the PRMS hydrologic model), a relationship was developed between historical annual precipitation (gridded dataset developed by Maurer et al. [2002] was used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge.

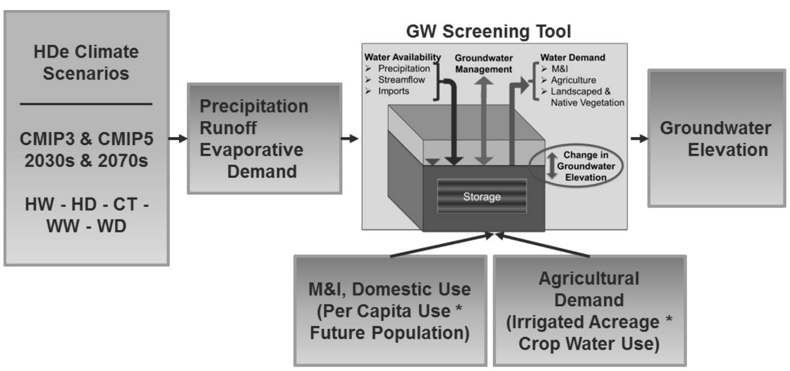
Although alternate relationships were explored in this study, a linear relationship between precipitation and recharge appeared to best represent the data. Such a relationship was developed using annual recharge and precipitation (at the spatial resolution of the VIC model), aggregated by recharge zone. Using the developed relationships between annual recharge and precipitation (by recharge zone) based on historical data, the same relationship was applied to each of the five HDe climate change scenarios of precipitation for two future time periods (2030s and 2070s) and for CMIP3 and CMIP5 projections. As a result, corresponding projections of recharge were developed at the VIC model resolution. These projections were used to generate annual change factors (based on ratios between projected recharge and MODFLOW historical), which were then applied to historical recharge uniformly over all MODFLOW grid cells within a corresponding VIC model grid cell.

*Caveats*
It should be noted that the described approach for developing projected surface water inputs to the Upper Klamath Basin MODFLOW model may introduce errors in the groundwater balance due to inconsistently developed inputs. For example, recharge and maximum ET projections were developed using established relationships between projections based on HDe scenarios and historical values used in MODFLOW historical simulations. Hence, they were not developed via an integrated surface water model. Despite the use of potentially inconsistent methodologies, this approach provides the best available estimates of projected surface inputs to the groundwater system.

**Scott and Shasta Valleys**
Projections of future groundwater elevation may be computed for the Scott and Shasta Valleys using the groundwater screening tools developed and described in Section 3.4, Historical Groundwater Availability. Similar to the Upper Klamath Basin, perturbed historical inputs representing projected conditions were used by the models to generate projections of groundwater elevation. Future projections were incorporated for climate and water balance input terms, as well as municipal, domestic, and industrial demand with respect to projected population.

Agricultural demand was left unchanged for the water supply assessment in order to focus on the impacts of climate change on groundwater elevation, and not changes in agricultural demand. Variations in historical agricultural demand are incorporated into historical groundwater elevations used to develop relationships in the computation of groundwater response. However, projected changes in temperature and precipitation will affect agricultural demand, which may markedly affect groundwater levels beyond what was experienced historically. In the discussions of climate change impacts on water demand in the watershed and associated risks and system reliability (Chapters 4 and 5 of this Klamath River Basin Study report, respectively), we address projected changes in agricultural demand and how the watershed may be impacted by the compounded stresses associated with climate change (with and without management adaptations).

Specific projected inputs to the groundwater screening tools for the Scott and Shasta Valleys are further described below. An overview diagram illustrating how projected inputs are incorporated into the groundwater screening tools is provided in Figure 3-23.




** Paleo-Conditioned Streamflow to provide context for projected surplus and drought spells*

**Figure 3-23. Approach for assessment of projected groundwater supplies in the Scott and Shasta Valleys**

Future projections of monthly mean precipitation and daily mean temperature (surrogate for evaporative demand) computed over the groundwater basins were input to the groundwater screening tools for each basin. These climate scenarios were based on the five HDe climate change scenarios for two future time horizons (2030s and 2070s) as well as for projections based on both CMIP3 and CMIP5. Similar projections of mean monthly runoff over each of the groundwater basins were also input to the models.

It should be noted that the approaches described above for developing projected surface water inputs to the Scott and Shasta Valley groundwater screening tools (including precipitation, temperature, and runoff) are compatible. These inputs rely on HDe climate scenarios themselves (in the case of precipitation and temperature) or outputs generated by the VIC model (runoff) whose simulations rely on HDe climate scenarios.

Municipal, industrial, and domestic water demand, which was computed based on the product of per capita water use and population, was perturbed according to projected population growth. Per capita use was assumed to remain constant. Projected population for each of the two future time horizons (2030s and 2070s) was computed by assuming a percent increase in population equal to the percent change between 1990 and 2000, which was documented by the 2000 Census.[5] For the Scott Valley this was +1.93 percent, while for the Shasta Valley it was +2.01 percent over ten years. The mean of projected population 2020–2050 was used to represent 2030s population, while the mean of projected population 2060–2080 was used to represent 2070s population. Additional scenarios of population growth were not considered as part of the water supply assessment; however, additional scenarios may be considered in subsequent stages of the Klamath River Basin Study as part of the analysis of management alternatives and/or adaptation strategies.

As previously mentioned, agricultural water demands were not modified as part of the evaluation of climate change impacts on groundwater elevations in the Scott and Shasta Valleys. The primary reason changes in agricultural demand were not considered here is that detailed analysis of the implications of projected agricultural demand is part of the assessment of current and future water demands in Chapter 4.

## 3.6 Comparison between CMIP3 and CMIP5

Projections of climate as well as surface water and groundwater hydrologic variables were summarized using both CMIP3- and CMIP5-based projections to understand whether these projections provide a similar view of future conditions. Few studies exist to provide guidance on whether the more recent CMIP5 projections ought to supersede those from CMIP3, whether they are similar enough that one or the other may be used, or whether they ought to be used collectively in impacts assessments. The intent of the Klamath River Basin Study water supply assessment is not to provide such guidance, but instead to evaluate the impacts of climate change using both sources of projections to provide the most comprehensive understanding possible of projected changes in water supply in the watershed.

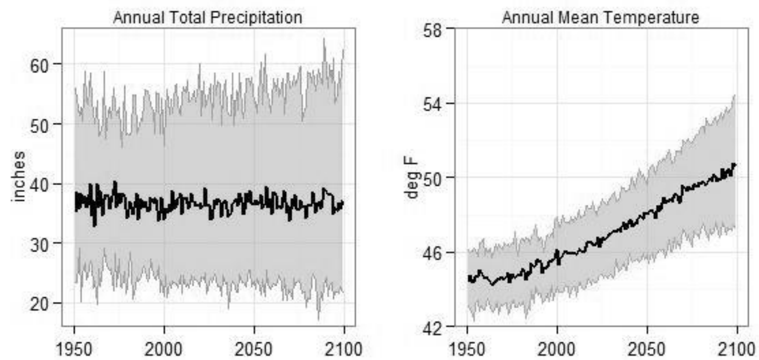
[5] http://www.ncdc.noaa.gov/climate/research/population/

### 3.6.1 Climate

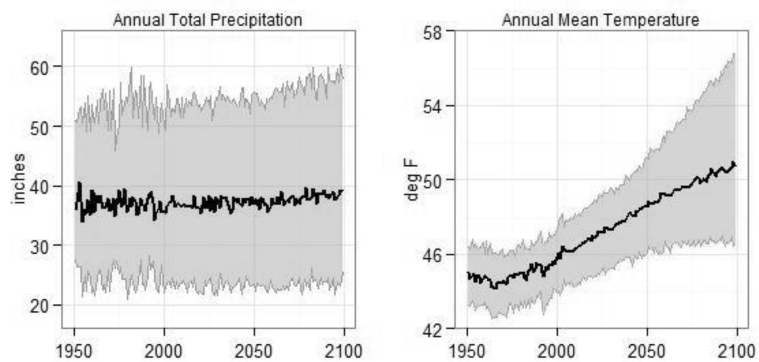
The basis for the five HDe climate change scenarios of precipitation and temperature (minimum and maximum) used throughout the Klamath River Basin water supply assessment is a suite of monthly statistically downscaled GCM simulations, based on CMIP3 and CMIP5 projections. As described in detail in Section 3.5.1.1, Climate Projections, HDe scenarios are generated by computing change factors between designated future time horizons (in this case the 2030s and 2070s) and a designated historical period (in this case 1970–1999).

Figure 3-24 illustrates the envelopes of projected mean annual precipitation and temperature as they evolve through time (i.e., light red on the top panel for temperature and light blue on the bottom panel for precipitation). All projections show that the region will become warmer during the 21st century, with greater uncertainty in annual temperature farther into the future as shown by the widening swath of projections. Annual precipitation in the Klamath River Basin is projected to increase slightly through time. However, it should be noted that this slight projected increase (both for CMIP3 and CMIP5 projections) is within the range of historical variability in precipitation from year to year. In contrast, for temperature, the median projection shows that temperatures will exceed the range of historical year to year variability by about 2050.

A comparison of CMIP3 and CMIP5 projections shows that trajectories through time appear similar; however, the range of projected precipitation is similar between the two types of projections, while projected temperature appears greater with CMIP5 projections. The larger projected range in projected temperature is likely due to the consideration of the full range of emissions scenarios for both CMIP3- and CMIP5-based projections. As shown in Figure 3-24, the range of projected global warming is greater for CMIP5 scenarios than for CMIP3.




a) **CMIP3**




**b) CMIP5**

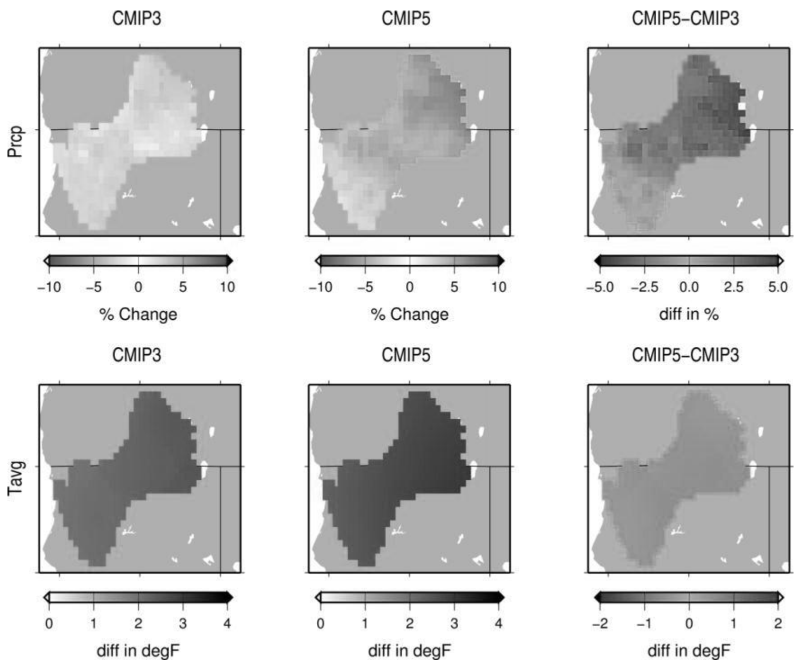
Note: The top row (a) and bottom row (b) illustrate the range of CMIP3 projections and CMIP5 projections, respectively. The black line in each panel shows the median of annual projections, while the colored band represents the range of all GCM projections (112 for CMIP3 and 234 for CMIP5).

**Figure 3-24. Summary of statistically downscaled GCM projections of mean annual precipitation and temperature from 1950 to 2100**

Figure 3-25 shows projected changes in mean annual precipitation (in percent) and average temperature (in degrees F) for the 2030s, compared with the historical baseline (1950–1999), using both CMIP3- and CMIP5-based HDe scenarios, while Figure 3-26 shows similar projections for the 2070s. It should be noted that these projections do not reflect information from the paleo record, as paleo-conditioned projections only correspond with streamflow. The projections shown in the figures represent the central tendency derived using the HDe approach. Each figure shows projections based on CMIP3 in the left panel,

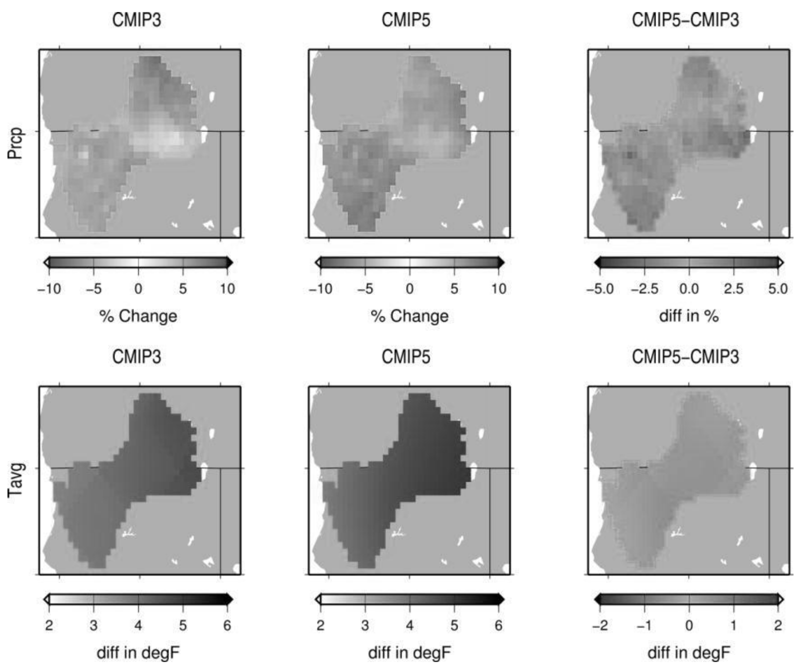
projections based on CMIP5 in the middle panel, and the difference between CMIP5 and CMIP3 in the right panel.

Projected changes in precipitation and temperature are positive for both CMIP3 and CMIP5 for the 2030s and 2070s. As can be seen in Table 3-5, which summarizes spatially averaged projected changes for both time horizons and over three dominant Klamath River Basin climate divisions as well as the basin as a whole, there are notable differences in the magnitude of projected change.




Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

**Figure 3-25. Comparison of percent change (2030s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5**




Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

**Figure 3-26. Comparison of percent change (2070s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5**

For the 2030s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the North Coast Drainage, which is located at the California portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 4.1 percent increase in mean annual precipitation, while CMIP3-based scenarios indicate a 2.4 percent increase by the 2030s. CMIP5-based scenarios are noticeably wetter than CMIP3 in the eastern portions of the High Plateau and South Central climate divisions. However, CMIP5-based scenarios are noticeably drier in the southernmost portion of the watershed, as previously mentioned. With respect to mean annual average temperature for the 2030s, CMIP5 projections indicate a greater increase in temperature than CMIP3 for all spatial domains considered (see Figure 3-2), although the projections are not substantially different. Projected temperatures basin-wide for the 2030s central

tendency show an increase of 2.2 degrees F for CMIP3 and 2.7 degrees F for CMIP5.

For the 2070s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the High Plateau, which is located at the northernmost portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 6.1 percent increase in mean annual precipitation, while CMIP3 projections indicate a 5.2 percent increase by the 2070s. With respect to mean annual average temperature for the 2070s, CMIP5 projections indicate a greater increase in temperature than CMIP3 projections for all spatial domains, which is similar to results for the 2030s. Projected temperatures basin-wide for the 2070s central tendency indicate an increase of 4.2 degrees F for CMIP3 and 4.5 degrees F for CMIP5.

## CMIP3 and CMIP5 Comparison – Precipitation and Temperature

Ranges of projected precipitation appear similar while ranges of temperature appear greater with CMIP5 than with CMIP3 scenarios. Spatial differences between CMIP3 and CMIP5 scenarios may be due to internal variability in the model simulations and HDe scenario development. By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

Although the magnitude differences are quite similar between CMIP3 and CMIP5 for precipitation and temperature for each future time horizon (central tendency), the spatial differences between CMIP3 and CMIP5 are interesting (see the right panels of Figures 3-25 and 3-26). For the 2030s, CMIP3 projections show less increase in precipitation that CMIP5 in the lowermost portion of the Klamath River Basin, while also showing a larger increase in the easternmost portion of the basin. For the 2070s, CMIP3 projections show less increase in precipitation in the Oregon portion of the basin than CMIP5 projections, while in most other parts of the basin CMIP5 projections show greater increase. The spatial differences between CMIP3- and CMIP5-based scenarios may be due to internal variability in the model simulations, and therefore the spatial patterns should be viewed collectively as potential future conditions.

**Table 3-5. Summary of projected changes in mean annual precipitation and average temperature for the 2070s, compared with the historical baseline**

**(1950–1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions**

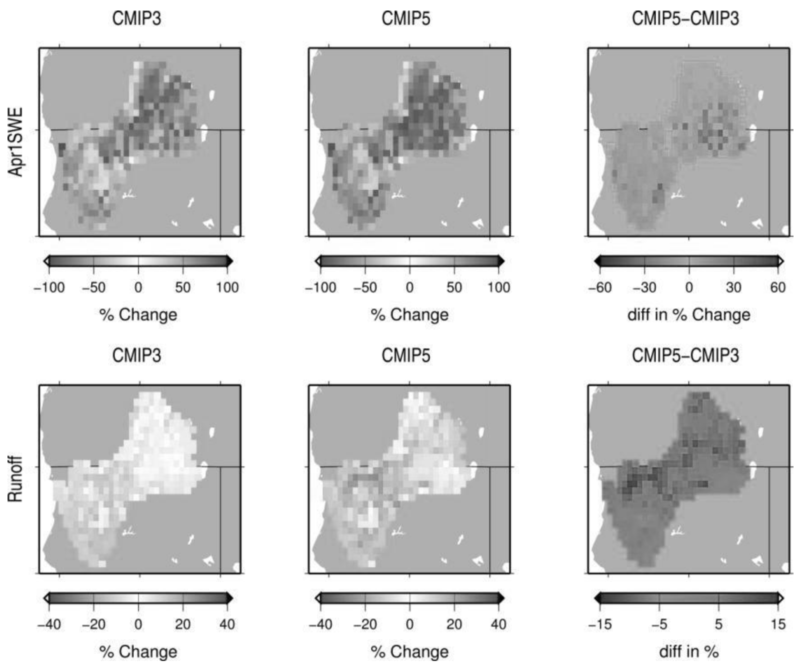
| Climate Division | Basinwide | North Coast Drainage | South Central | High Plateau |
|---|---|---|---|---|
| **2030s** | | | | |
| Prcp, CMIP3 | +2.4 % | +2.3 % | +2.4 % | +2.7 % |
| Prcp, CMIP5 | +4.1 % | +3.6 % | +5.4 % | +5.8 % |
| Tavg, CMIP3 | +2.2 degF | +2.2 degF | +2.3 degF | +2.4 degF |
| Tavg, CMIP5 | +2.7 degF | +2.6 degF | +2.8 degF | +2.8 degF |
| **2070s** | | | | |
| Prcp, CMIP3 | +5.2 % | +5.0 % | +5.1 % | +6.4 % |
| Prcp, CMIP5 | +6.1 % | +6.3 % | +5.3 % | +5.7 % |
| Tavg, CMIP3 | +4.2 degF | +4.1 degF | +4.3 degF | +4.4 degF |
| Tavg, CMIP5 | +4.5 degF | +4.4 degF | +4.7 degF | +4.7 degF |

### 3.6.2 Water Balance

Comparisons of CMIP3 and CMIP5 projections of April 1 SWE and mean annual runoff, both calculated using the VIC model, are illustrated in Figure 3-27 for the 2030s and Figure 3-28 for the 2070s and summarized in Table 3-6. Projections of snowpack on April 1 are presented, in part, because this is a common measure often used in climate change impact studies across the western U.S., but also because historical snowpack is at, or just past, its peak in early April and this measure is often used by water managers as a measure of spring and summer water supply. For the 2070s, CMIP3- and CMIP5-based projections of April 1 SWE show a similar magnitude of change and slight spatial differences (refer to Figure 3-28, upper left and upper central panels). The water balance terms are influenced by changes in precipitation and temperature across the landscape. Although both CMIP3 and CMIP5 projections indicate declines in April 1 SWE by roughly 30 to 40 percent by the 2030s and 60 percent by the 2070s for the central tendency, despite projected increases in annual runoff (see Table 3-5 for computed percent change over the basin and three dominant climate divisions).

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



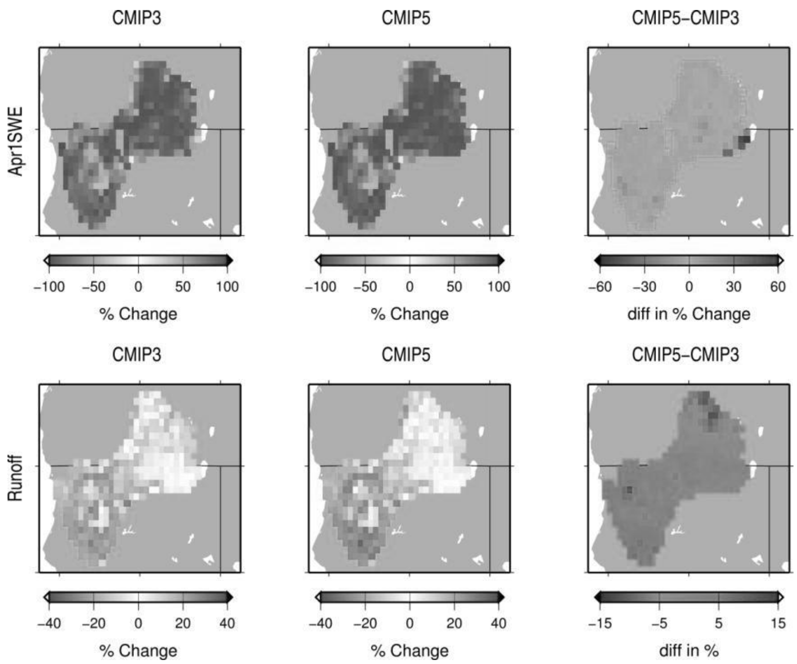



Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

**Figure 3-27. Comparison of percent change (2030s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios based on CMIP3 and CMIP5**

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...






Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

**Figure 3-28. Comparison of percent change (2070s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios, based on CMIP3 and CMIP5**

For both future time horizons, greater decreases in snowpack are projected for lower elevation regions while mountainous parts of the basin, namely the Cascades and Trinity Alps, show smaller projected decreases in April 1 SWE. Further, for the VIC model pixel that contains Mount Shasta (refer to the white square in the central area of the upper left and upper central panels of Figure 3-27 and Figure 3-28), snowpack is not projected to change substantially, likely due to the combined effects of its relatively high elevation, projected increases in precipitation, and projected increases in temperature.

The upper right panels of Figure 3-27 and Figure 3-28 show the differences in April 1 SWE between CMIP3 and CMIP5 projections. Although differences for the 2030s and 2070s central tendency are small, the CMIP3 projection indicates a larger decrease in snowpack than CMIP5 in parts of the Upper Klamath Basin for the 2030s and the easternmost portion of the basin in California for the 2070s. Smaller differences in April 1 SWE are projected for the 2070s. Mean percent

change in April 1 SWE across the Klamath River Basin is -33.8 percent for the 2030s and -58.2 percent for the 2070s.

**Table 3-6. Summary of projected changes in April 1 SWE and annual runoff for the 2030s compared with the historical baseline (1950-1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions**

| Climate Division | Basinwide | High Plateau | South Central | North Coast Drainage |
|---|---|---|---|---|
| **2030s** | | | | |
| **Apr1 SWE, CMIP3** | -33.8 % | -38.9 % | -31.0 % | -32.5 % |
| **Apr1 SWE, CMIP5** | -39.8 % | -41.4 % | -35.4 % | -39.8 % |
| **Ann Runoff, CMIP3** | +7.3 % | +1.4 % | -0.6 % | +8.8% |
| **Ann Runoff, CMIP5** | +11.6% | +3.4 % | +4.6 % | +12.9 % |
| **2070s** | | | | |
| **Apr1 SWE, CMIP3** | -58.2 % | -61.9 % | -54.7 % | -57.3 % |
| **Apr1 SWE, CMIP5** | -62.0 % | -65.6 % | -58.8 % | -61.1 % |
| **Ann Runoff, CMIP3** | +13.9 % | +0.1 % | -0.5 % | +16.4 % |
| **Ann Runoff, CMIP5** | +15.3 % | -5.1 % | -2.5 % | +18.7 % |

According to projections based on both CMIP3 and CMIP5 for the 2030s and 2070s, mean annual runoff is projected to increase in the Lower Klamath Basin while changes in the Upper Klamath Basin vary both in magnitude and direction and between CMIP3 and CMIP5 (refer to lower panels of Figure 3-27 and Figure 3-28). Projected changes in runoff based on climate division show increases in the North Coast Drainage on the order of 16 or 19 percent (for CMIP3 and CMIP5, respectively) for the 2070s central tendency and decreases across the South Central climate division on the order of 1 to 3 percent (for CMIP3 and CMIP5, respectively). Across the High Plateau (the region upstream and to the east of Upper Klamath Lake; refer to Figure 3-2), projections are mixed, with CMIP3-based projections indicating a slight increase in mean annual runoff and CMIP5-based projections indicating a decrease in mean annual runoff for the 2070s. The lower right panels of Figure 3-27 and Figure 3-28 illustrate the spatial difference between CMIP3 and CMIP5 for the 2030s and 2070s, respectively. For the 2030s, CMIP5 projections indicate greater changes in runoff over the mainstem Klamath River area than CMIP3, yet smaller changes in runoff over the higher elevation regions of the Trinity River basin and Tule Lake area. For the 2070s, CMIP5 projects lower runoff change than

## CMIP3 and CMIP5 Comparison – Water Balance

CMIP3 and CMIP5 water balance projections are largely consistent, indicating decreases in April 1 SWE on the order of 34-40 percent for the 2030s and close to 60 percent for the 2070s, and increases in annual runoff of 7-12 percent for the 2030s and 14-15 percent for the 2070s.

CMIP3 in the Upper Klamath Basin and lower runoff change than CMIP3 in the Lower Klamath Basin.

The differences between CMIP3 and CMIP5 projections for the 2070s central tendency in projected precipitation, temperature, snowpack, and runoff show great similarities in the central tendency scenario for the Klamath River Basin as a whole. However, there are notable differences in that CMIP5 projections tend to be wetter and warmer over the Klamath River Basin than those from CMIP3. Also, there are notable spatial differences that are important to consider when relying on projections from either CMIP3 or CMIP5 (but not both) for water management decision-making.

## 3.7 Future Availability

Projected availability of surface water and groundwater in the Klamath River Basin was assessed by evaluating changes in seasonal precipitation and temperature, snowpack, timing and quantity of runoff, soil moisture and ET, low flow frequency, and groundwater recharge and discharge. For the most part, this assessment focuses on projections based on CMIP5; however, corresponding results based on CMIP3 projections were also developed and are included in Appendix B, Supplemental Information for Assessment of Water Supply.

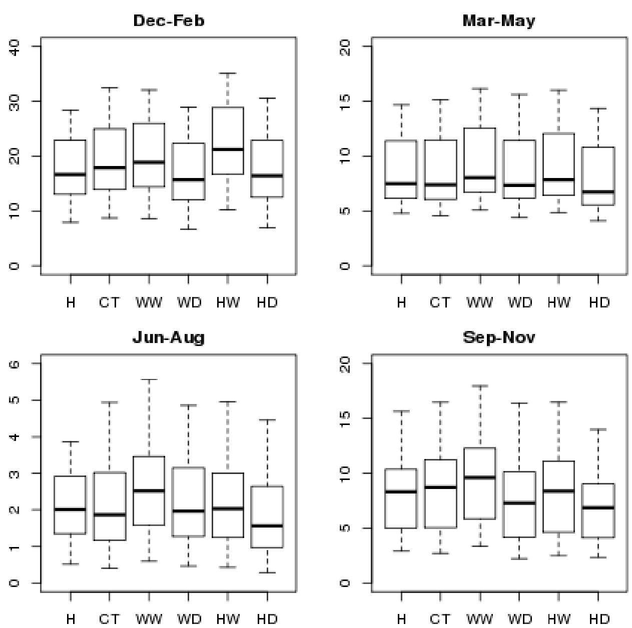
Figure 3-29 illustrates projections of seasonal basin mean precipitation for the 2070s compared with the historical period, based on CMIP5. Each panel includes box plots of historical and projected precipitation, where the boxes represent the 25th, 50th, and 75th percentile values for seasonal precipitation averaged across the Klamath River Basin, and the whiskers represent the 5th and 95th percentile values.

> **Future Availability – Precipitation and Temperature**
>
> Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

In general, the box plots show that the majority of precipitation falls between December and February, an order of magnitude greater than between June and August. In winter (December through February; refer to upper left panel of Figure 3-33), central tendency, WW, and HW scenarios indicate an increase in precipitation, while the WD and HD scenarios indicate decreases in precipitation over this time period. The range between 5th and 95th percentile values across each of the five HDe climate change scenarios appears similar. Projections for the spring period between March and May (upper right panel) and the autumn period between September and November (lower right panel) appear similar to historical conditions, with slight increases for the wetter scenarios (WW and HW) and slight decreases for the drier scenarios (WD and HD). Projections for the summer period (June through August; refer to lower

left panel) show a slight decrease in the median of the central tendency scenarios compared with historical, and decreases in general for the drier scenarios and increases for the wetter scenarios. However, it is notable that the WW scenario indicates a larger increase in summer precipitation than the HW scenario.

It is important to mention that HDe climate change scenarios were developed based on projected changes from multiple GCMs in annual precipitation and temperature across the basin, potentially dampening the signal toward drier summers and wetter winters (as shown in Figure 3-19). Also, the Klamath River Basin water supply assessment does not evaluate projected changes in extreme precipitation events, which are also likely to change as a result of climate change. The focus of this water supply assessment is on the watershed's overall monthly to seasonal water balance, rather than the effects of individual storm events.

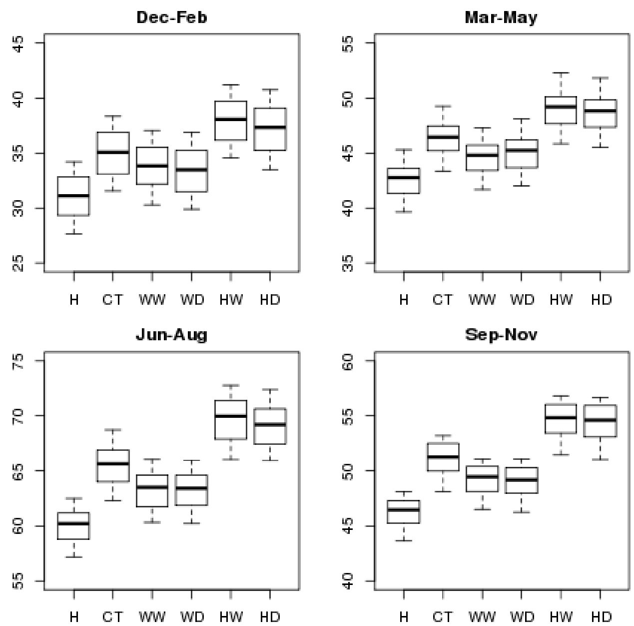



Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

**Figure 3-29. Seasonal basin mean precipitation (in inches), CMIP5 2070s and historical (1950–1999)**

Projections of seasonal temperatures for the 2070s, compared with the historical period (1950–1999) show similar patterns in HDe climate change scenarios across

seasons (refer to Figure 3-30). The hotter HDe scenarios (HW and HD) indicate warmer temperatures relative to the warmer HDe scenarios (WW and WD), compared with historical temperatures. Central tendency scenarios tend to fall in between the warmer and hotter scenarios. What is notable about the seasonal temperature projections is that, for all seasons, the hotter HDe scenarios are mostly outside the range of corresponding historical seasonal temperatures. In summer and fall, even the central tendency HDe scenarios are mostly outside the range of historical temperatures.

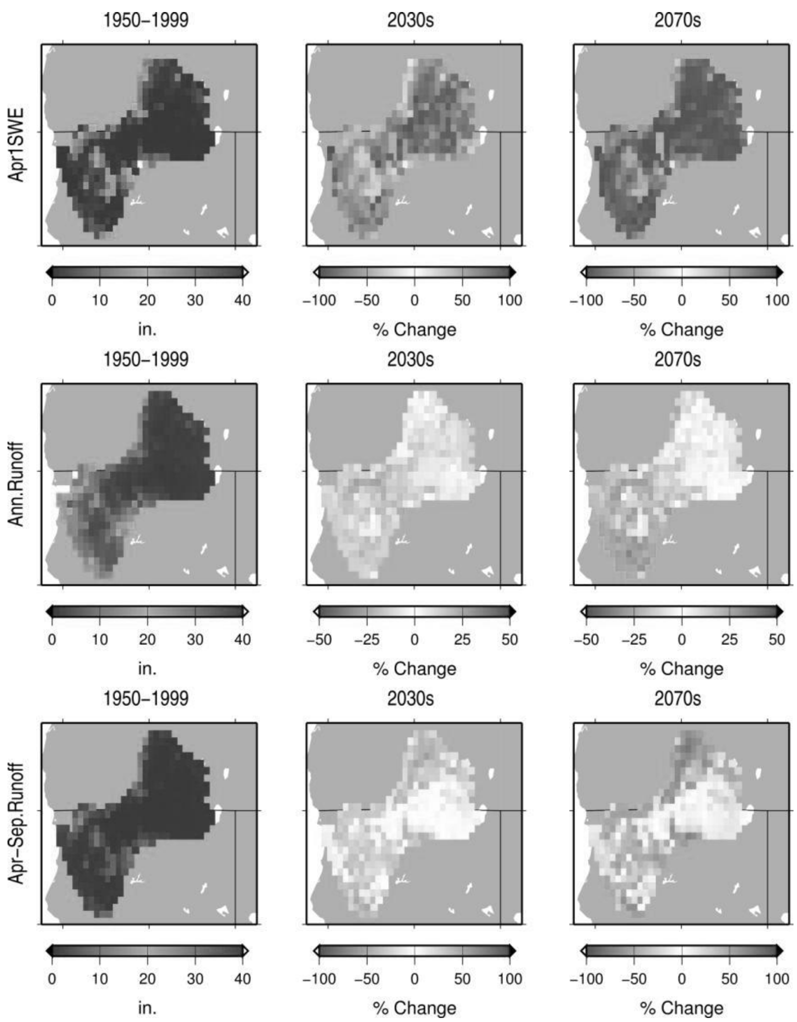



Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

**Figure 3-30. Seasonal basin mean daily average temperature (in degrees F), CMIP5 2070s and historical (1950–1999)**

### 3.7.1 Changes in Water Balance Terms

This section summarizes projected spatial and basin mean changes in snowpack, annual and spring runoff, soil moisture, and actual ET for the two future time horizons (2030s and 2070s), based on central tendency CMIP5 projections. Figures corresponding to those shown in this section based on CMIP3 projections are included in Appendix B, Supplemental Information for Assessment of Water Supply. It should be noted that paleo-conditioned streamflow projections were not incorporated into the analysis of climate change impacts on surface water balance variables. Figures 3-31 and 3-32 are similar in format in that the left column illustrates mean historical conditions over the period 1950–1999. The middle column illustrates projected percent change for the 2030s future time horizon compared with historical, while the right column illustrates projected percent change for the 2070s future time horizon compared with historical.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

**Figure 3-31. Comparison of percent change in mean April 1 SWE, mean annual runoff, and mean April-September runoff for the central tendency HDe scenarios based on CMIP5**

Mean historical SWE on April 1 (Figure 3-31, top row) falls within the range of little or no snow in the coastal region to almost 40 inches of SWE in the Cascade

Mountains (and even greater snowpack at Mount Shasta). Based on CMIP5 projections, mean percent change in April 1 SWE across the Klamath River Basin is -40 percent for the 2030s and -62percent for the 2070s. Greater decreases are projected for middle to lower elevation parts of the basin. Snowpack at Mount Shasta is expected to exhibit little change (on a percent basis) by the 2030s or 2070s.

Historical mean annual runoff over the 1950–1999 period ranges from a little less than 1 inch in the northeastern part of the basin to more than 40 inches in parts of the coastal region and near Mount Shasta. Basin-wide mean percent change in annual runoff is +12 percent for the 2030s and +15 percent for the 2070s. Most of the Lower Klamath Basin is projected to experience increases in mean annual runoff, while the Cascades region is projected to experience decreases. What is notable with respect to projected changes in mean annual runoff in the Upper Klamath Basin is that projected increases in runoff appear greater for the 2030s than the 2070s. This is likely due to the combined effects of projected increases in precipitation along with projected increases in temperature. For the 2030s, increased precipitation dominates the water balance, resulting in larger increases in annual runoff, while for the 2070s corresponding increases in temperature may cause actual ET to be great enough to show an overall smaller increase in mean annual runoff than for the 2030s.

## Future Availability – Water Balance

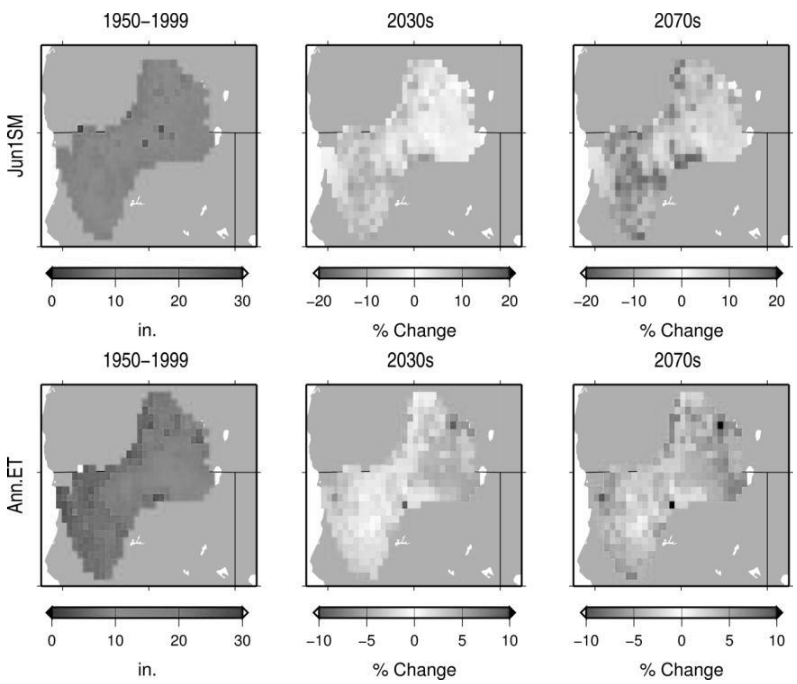
Mean percent change based on CMIP5 central tendency projections includes:

- April 1 SWE: -40 percent (2030s) and -62 percent (2070s)
- Spring (April–September) runoff: -25 percent (2030s) and -40 percent (2070s)
- June 1 soil moisture: -4.9 percent (2030s) and -8.7 percent (2070s)
- Annual ET: +2.6 percent (2030s) and +4.1 percent (2070s)

Historical irrigation season (April through September) runoff over the 1950–1999 period ranges from less than 1 inch to about 30 inches, with higher spring runoff occurring in the mountainous parts of the Klamath River Basin. Mean percent change in spring (April through September) runoff is -25 percent for the 2030s and -40 percent for the 2070s.

Similar to evaluating snowpack at its general peak, projections of soil moisture on June 1 are presented because, in the absence of irrigation or other water management, June is the month of greatest soil moisture throughout the Klamath River Basin. Changes in maximum soil moisture may be of interest to water managers in terms of understanding projected changes in groundwater and soil water availability. Mean historical soil moisture on June 1 over the period 1950–

1999 ranges from less than 1 inch to almost 30 inches, with the greatest soil moisture occurring in mountainous regions with melting snowpack and generally higher precipitation (Figure 3-32). Mean percent change in June 1 soil moisture across the Klamath River Basin is a reduction by 4.9 percent for the 2030s and a reduction by 8.7 percent for the 2070s, compared with the historical period. The pattern of projected change in June 1 soil moisture is similar to that of spring runoff, indicating that projected reductions in soil moisture correspond with reductions in spring runoff. Interestingly, these reductions also correspond with projected increases in mean annual runoff, indicating that there may be a seasonal shift in runoff (discussed in the next section), and therefore June 1 soil moisture.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

**Figure 3-32. Comparison of percent change in mean June 1 soil moisture and mean annual evapotranspiration for the central tendency climate scenario, using groupings of GCMs from CMIP5**

Mean historical annual ET over the period 1950–1999 ranges from less than 10 inches to about 33 inches (Figure 3-32). Higher ET values tend to occur in regions with greater water availability (i.e., greater precipitation), like in the Lower Klamath Basin and other mountainous regions. Mean percent change in annual ET basin wide is +2.6 percent for the 2030s and +4.1 percent for the

2070s. Larger percentage increases in ET appear to be projected for parts of the Upper Klamath Basin. However, these results may not reflect relative increases in the amount of water lost to ET, due to the fact that the Upper Klamath Basin generally has lower annual ET.

Figure B-12 in Appendix B, Supplemental Information for Assessment of Water Supply, illustrates projected changes in June 1 soil moisture and mean annual ET for the 2030s and 2070s central tendency, based on the CMIP3 HDe scenarios. Results are similar in spatial patterns of projected change; however, CMIP3-based projections generally indicate smaller projected changes in June 1 soil moisture and annual ET than CMIP5.

### 3.7.2 Changes in Timing and Quantity of Runoff

This section evaluates projected changes in mean monthly streamflow at selected locations within the Klamath River Basin, the projected shift in timing of mean monthly hydrographs for one example location within the basin, and low flow frequency statistics for select locations. Analyses focus on projected changes for the two future time horizons (2030s and 2070s) based on CMIP5 projections. Figures similar to those presented in this section, but based on CMIP3 projections, are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, the presentation of projected streamflow results at Keno, Oregon (Figure 3-33) includes projections based on both CMIP3 and CMIP5 to allow for direct comparison of mean monthly hydrographs under various types of projections.

Simulated historical and projected mean monthly hydrographs for the Klamath River at Keno, Oregon are presented in Figure 3-33 to illustrate an example of projected changes in overall flow volume and seasonal peak timing of streamflow in the watershed. The top two panels summarize projections based on CMIP3 projections, while the bottom two panels summarize projections based on CMIP5 projections. The mean monthly historical hydrograph is identical in each panel and was computed over water years 1950–1999 (i.e., September 1949–October 1999).

Both CMIP3- and CMIP5-based projections indicate a decrease in spring and summer streamflow for the 2030s and a greater decrease by the 2070s. The wetter of the five HDe climate change scenarios (HW and WW) indicate greater streamflow volume overall, along with higher seasonal peaks. Drier scenarios (HD and WD) indicate reduced streamflow volumes and reduced peaks. Projections for the 2030s (based both on CMIP3 and CMIP5) indicate a shift in seasonal peak timing from approximately zero to one month earlier (a shift from April to March). For the 2070s, projected shifts in seasonal peak timing are zero to two months earlier (a shift from April to as early as February).

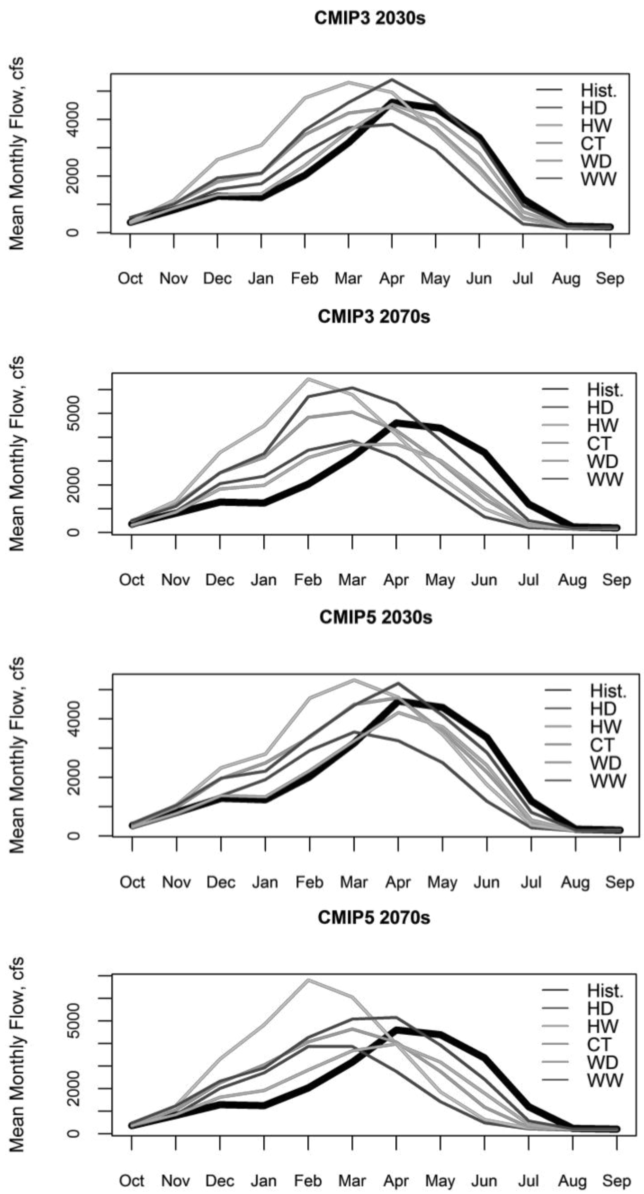



**Figure 3-33. Historical and projected mean monthly hydrographs for Klamath River at Keno, OR (USGS ID 11509500)**

The projected shifts in streamflow volume and timing for Keno, Oregon are typical of those sub-basins within the Klamath River Basin that are influenced in part by snowmelt. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume. Wetter scenarios indicate greater increases, while drier scenarios indicate anywhere from a slight decrease in flow volume to a slight increase in flow volume (figures not shown).

The seasonality of streamflow, in particular low flow periods, is of interest to water managers since there is often limited supply for numerous competing resources during low flow periods. At the same time, natural streamflow variability, including low flows, serves an important function for a river ecosystem. Richter et al. (1997) discuss an approach for setting streamflow-based targets for ecosystem management. The approach is based on the notion that streamflow characteristics are useful indicators for assessing ecosystem integrity over time. One of the identified indicators is the annual 7 day minimum of flow. As part of the assessment of future water supply, we evaluated projected changes in the 7Q10 low flow frequency statistic. This statistic is defined as the lowest 7 day mean flow at a location, occurring at a 10 year recurrence interval. As one example of its application, this statistic is used to define the “critical condition” for adverse impact on aquatic biota in Washington state (Chapter 173-201A of the Washington Administrative Code). As part of this assessment, the 7Q10 low flow frequency statistic is evaluated for a number of sites throughout the Klamath River Basin.

Projected changes in the 7Q10 low flow frequency statistic were evaluated as part of the Klamath River Basin water supply assessment as a way of focusing on changes in streamflow during their seasonal low periods. Low flow periods typically occur in late summer when precipitation is low, stored water supplies have largely been consumed, and anadromous fish species begin their upstream migration to spawning grounds.

Table 3-7 summarizes projected changes in 7Q10 low flow frequency for eight selected sites throughout the Klamath River Basin. Primary projected values in the table represent the central tendency, while the values in parenthesis represent the range of the five HDe climate change scenarios for CMIP3 and CMIP5 for each future time horizon. Projected changes were computed as a ratio between the projected value and the historical value. Values greater than one indicate an increase in the 7Q10 low flow, while values less than one indicate a decrease in the 7Q10 low flow (these are shown in bold in the table).

**Table 3-7. Summary of ratios between projected and historical 7Q10 low flow frequency statistics for various sites within the Klamath River Basin**

| Site ID | Site Name | Hist. 7Q10 (cfs) | 2030s CMIP3 | 2030s CMIP5 | 2070s CMIP3 | 2070s CMIP5 |
|---|---|---|---|---|---|---|
| 00020 | Sprague R near Chiloquin | 68.6 | 1.03 (**0.943**-1.06) | 1.00 (**0.955**-1.05) | 1.01 (**0.917**-1.07) | 1.01 (**0.927**-1.07) |
| 00026 | Klamath R blw Iron Gate Dam | 167 | **0.989** (**0.965**-1.01) | **0.989** (**0.970**-1.01) | **0.994** (**0.949**-1.01) | **0.995** (**0.952**-1.01) |
| 00004 | Klamath R at Orleans | 313 | **0.998** (**0.980**-1.01) | **0.995** (**0.982**-1.01) | **0.996** (**0.969**-1.01) | **0.994** (**0.977**-1.01) |
| 00029 | Klamath R near Klamath | 443 | 1.00 (**0.983**-1.00) | **0.997** (**0.989**-1.00) | **0.998** (**0.977**-1.00) | **0.996** (**0.981**-1.00) |
| 00022 | Salmon R at Somes Bar | 23.4 | **0.966** (**0.932**-1.01) | **0.979** (**0.957-0.966**) | **0.949** (**0.940-0.996**) | **0.983** (**0.953-0.987**) |
| 00031 | Shasta R near Yreka | 29.2 | 1.01 (**0.990**-1.01) | 1.01 (**0.979**-1.01) | 1.02 (**0.990**-1.02) | 1.02 (**0.979**-1.02) |
| 00032 | Scott R near Ft Jones | 25.9 | 1.02 (1.01-1.04) | 1.04 (1.01-1.05) | **0.996** (**0.996**-1.03) | 1.07 (**0.981**-1.07) |
| 00034 | Trinity R at Hoopa | 99.4 | 1.01 (1.00-1.01) | 1.01 (1.00-1.02) | 1.02 (1.00-1.02) | 1.01 (1.01-1.02) |

Note: Primary values represent the central tendency HDe scenario. Values in parenthesis represent the range of the five HDe climate change scenarios. Values above 1 indicate an increase. Values less than 1 indicate a decrease (shown in bold).

Select sites on the Sprague, Shasta, Scott, and Trinity Rivers are projected to experience increases in 7Q10 low flows for the 2030s and 2070s central tendency, compared with the historical period; however, projections range from slight decreases to slight increases. Projected increases are largely due to projected increases in precipitation. The Trinity River site (00034) is the only site evaluated where the entire range of projections indicate an increase in the 7Q10 low flow statistic. Select sites including three on the mainstem Klamath River (below Iron Gate Dam, at Orleans, and near Klamath) and one on the Salmon River are projected to experience decreases in the 7Q10 low flow central tendency, compared with the historical baseline; however, projections range from slight decreases to slight increases. The Salmon River site (00022) is the only one evaluated where the entire range (except for the 2030s CMIP3) indicates a decrease in the 7Q10 low flow statistic. Projected decreases are likely due to the combined effects of increased precipitation, increased temperature,

## Future Availability – Runoff Quantity and Timing

For those basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

and increased ET. It should be noted that projections based on CMIP3 and CMIP5 show similar results in their central tendency.

Projections shown in Table 3-7 are based on streamflow generated by the VIC hydrologic model which represents natural flow, absent of management effects such as withdrawals and groundwater pumping. Combined effects of changes due to climate change and changes in management practices may alleviate or exacerbate projected changes in low flows in the Klamath River Basin. It should be stressed that the historical values presented in Table 3-7 are lower than those typically experienced in the watershed. These values are based on the lowest 7-day running mean that has a 1:10 chance of occurrence. Such an occurrence would likely occur in a prolonged drought condition where groundwater levels (which would typically provide supplemental baseflow) are also negatively impacted. In addition, it should be noted that the VIC model does not represent complex surface and groundwater interactions and therefore may not generate realistic baseflow in a heavily groundwater influenced watershed such as the Klamath River Basin. Additional discussion related to VIC model limitations is provided in Appendix B, Supplemental Information for Assessment of Water Supply.

### 3.7.3 Changes in Drought and Surplus based on Paleo Conditioned Streamflow Projections

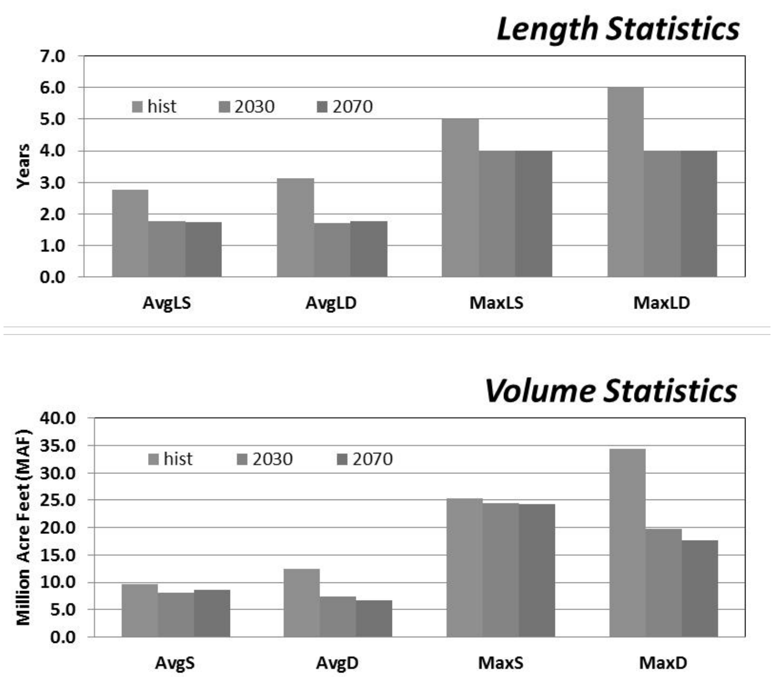
Using the approach described in Section 3.5.1.3, Deriving Paleo-Conditioned Streamflow Projections, drought and surplus statistics were analyzed for all HDe scenarios to characterize projected changes in droughts and surpluses. Drought and surplus statistics may be generated at any streamflow location in the Klamath River Basin using this approach. For the Klamath River Basin water supply assessment, we focus on results at the Klamath River near Klamath, California, which represents the integrated response to drought and surplus throughout the basin since it is close to the mouth of the river. Results are summarized graphically for the 2030s and 2070s for CMIP5-based central tendency scenarios in Figure 3-34. The data behind the figure, in addition to other HDe climate change scenarios, is summarized by Tables B-1 and B-2 in Appendix B, Supplemental Information for Assessment of Water Supply.

**Future Availability – Droughts and Wet Periods**

Analyses of surplus and drought statistics based on the paleo record are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes.

Overall, the surplus and drought statistics are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes. The projections correspond

with projections of increased precipitation overall in the Klamath River Basin for both future time horizons (2030s and 2070s). In spite of these statistics pointing to wetter conditions, the maximum surplus volumes are estimated to be nearly equal to the historical maximum surplus. The paleo-hydrologic analysis provides a way to superimpose variability by altering sequences, and for water systems the sequence in which wet and dry spells occur is critical.




Note: AvgLS and AvgLD: average length of surplus and drought, respectively. MaxLS and MaxLD: maximum length of surplus and drought, respectively. AvgS and AvgD: average surplus and drought, respectively MaxS and MaxD: maximum length of surplus and drought, respectively.

**Figure 3-34. Surplus and drought statistics for the paleo-conditioned CMIP-5 central tendency climate scenario**

### 3.7.4 Changes in Groundwater Supply

The impacts of climate change on groundwater supplies were evaluated for three primary groundwater basins within the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys. Similar to the assessment of surface water supplies, this assessment focuses on results based on CMIP5 projections. Figures similar to those presented below but based on

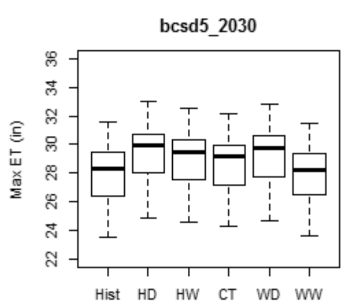
CMIP3 projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. This assessment also focuses on groundwater impacts as a result of projected changes in climate and surface water hydrology (as well as population for the Scott and Shasta Valleys) and does not consider changes in pumping or other changes in water management.

#### *3.7.4.1 Upper Klamath Basin*

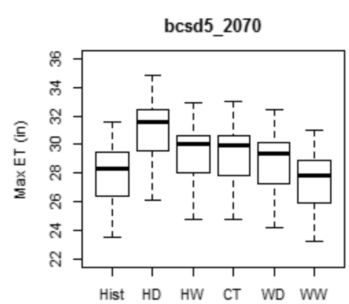
The following analysis of climate change impacts focuses first on the perturbed inputs of maximum ET and mean annual recharge for the projected MODFLOW simulations, and then on MODFLOW simulation results including projected changes in groundwater elevations and discharge to surface water.

**Inputs**

Projections for the three perturbed MODFLOW input terms are first discussed to provide context for the discussion of projected changes in groundwater elevations and discharge. Figure 3-35 shows historical and projected mean maximum ET (as defined in the approach) for the five HDe climate change scenarios on an annual basis. As described in the approach, projected maximum ET values were computed based on annual change factors applied to historical maximum ET. The figure shows that mean annual maximum ET is projected to increase for the 2030s and 2070s, compared with the historical period, when looking at corresponding percentile levels. For the 2030s, the drier scenarios (HD and WD) appear to have slightly larger increases than the wetter scenarios. For the 2070s, the HD scenario indicates a larger increase in maximum ET than all other scenarios.




a)




b)

Notes:

1. The heavy black line represents median of values across the 47 VIC cells within the Upper Klamath Basin MODFLOW model domain that contains evapotranspiration cells (defined by Gannett et al. [2012] Figure 4), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

**Figure 3-35. Summary of projected mean annual maximum ET for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years**

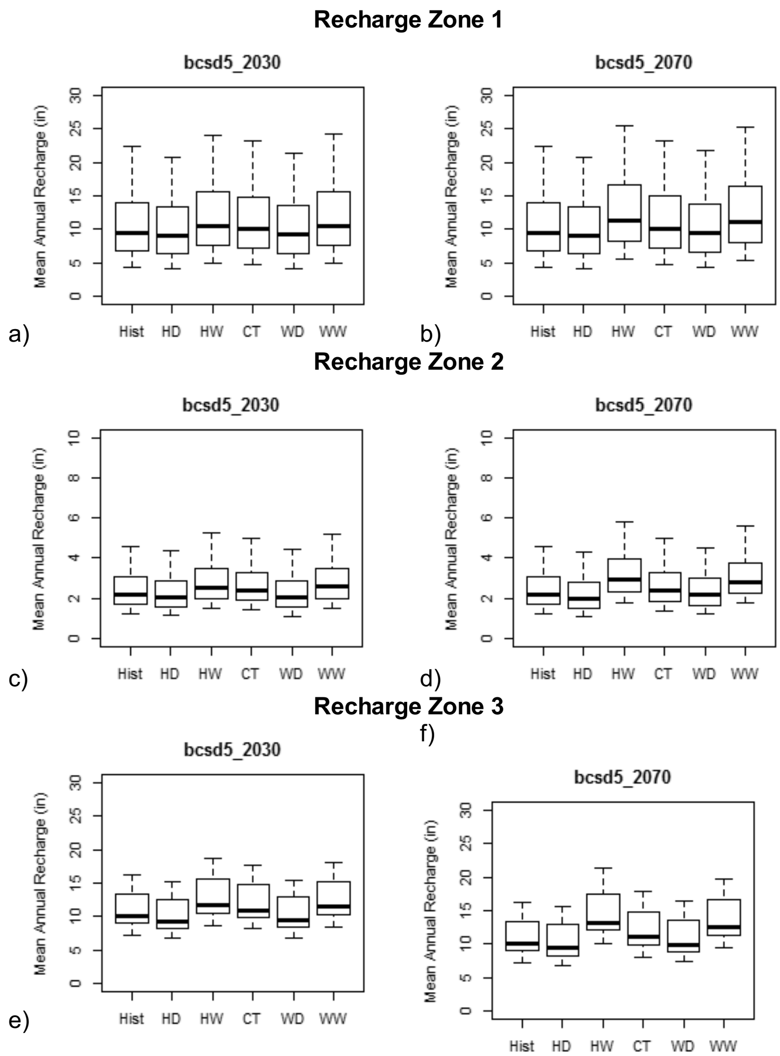
Table 3-8 summarizes the projected increases in the central tendency of mean annual maximum ET for the 2030s and 2070s, for projections based both on CMIP3 and CMIP5. Results show greater increases in maximum ET for projections based on CMIP3 than those based on CMIP5.

**Table 3-8. Summary of central tendency projections of maximum ET for the 2030s and 2070s, compared with the historical baseline (1970–1999).**

| Central Tendency Projections | 2030s | 2070s |
|---|---|---|
| CMIP3 | +4.5% | +7.1% |
| CMIP5 | +3.3% | +5.7% |

Projected recharge was input into future simulations of the Upper Klamath Basin MODFLOW model for five HDe climate change scenarios (for two future time periods and both CMIP3 and CMIP5), based on unique historical precipitation-recharge relationships by recharge zone. Figure 3-36 illustrates box plots of projected mean annual recharge by zone based on CMIP5 projections (refer to Figure 3-10 for identification of recharge zones). In general, projections of recharge are similar between future time horizons, both in magnitude and when considering the relative change across different climate change scenarios. Recharge zone 1 has a greater range of recharge (as evidenced by the difference between 5th and 95th percentile values) than zones 2 or 3. Also, recharge zone 2 has substantially lower recharge than the other zones, including the historical values. Lower recharge in zone 2 likely corresponds with less precipitation and snowpack to help drive recharge. Projected changes in mean annual recharge for zone 1 range from increases to small decreases. Wetter scenarios generally indicate increases in recharge, while drier scenarios generally indicate decreases, particularly looking at the median ($50^{th}$ percentile) change.

Table 3-8 summarizes mean annual recharge by zone, and basin-wide, for the central tendency (2030s and 2070s, CMIP3 and CMIP5). For the 2030s, projected changes in recharge differ substantially between CMIP3- and CMIP5-based scenarios. However, by the 2070s CMIP3- and CMIP5-based scenarios are more similar. In fact, the difference in projected recharge change for zone 1 is almost as great between CMIP3 and CMIP5 for the 2030s as the difference between the 2030s and 2070s based on CMIP3. These results were verified; however, it illustrates how closely recharge projections correspond with projections of future precipitation. Basin-wide precipitation changes for the central tendency are projected to be about +2.4 percent (based on CMIP3) and +4.1 percent (based on CMIP5) for the 2030s and about +5.2 percent (based on CMIP3) and +6.1 percent (based on CMIP5) for the 2070s. Projections of recharge for other HDe climate change scenarios show similar correspondence with precipitation projections.




Notes:

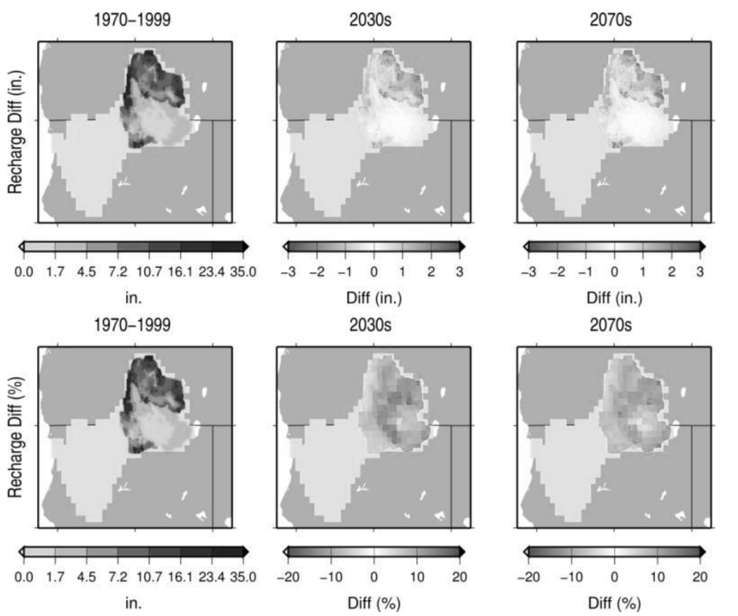
1. Heavy black line represents median of values across the 62 VIC cells within the MODFLOW model domain that are within recharge zone 1, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

**Figure 3-36. Summary of projected mean annual recharge for MODFLOW model recharge zone 1 for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years**

**Table 3-9. Summary of central tendency projected change in mean annual recharge by zone for the 2030s and 2070s, compared with the historical baseline (1970–1999 water years)**

| Central Tendency Projections | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| **Recharge Zone 1** | +3.0% | +6.1% | +7.9% | +6.5% |
| **Recharge Zone 2** | +4.3% | +8.9% | +8.0% | +9.4% |
| **Recharge Zone 3** | +4.6% | +8.8% | +10.5% | +10.0% |
| **Basin Wide** | +3.4% | +8.4% | +8.8% | +8.2% |

Figure 3-37 spatially illustrates historical and projected change in mean recharge for CMIP5-based central tendency scenarios (2030s and 2070s) based on data used as input by the MODFLOW model for the Upper Klamath Basin. The left column contains identical panels (top row and bottom row) showing the historical seasonal mean recharge (in inches) used in the calibrated model (similar to Figure 3-10). The middle and right columns contain projected change for the 2030s and 2070s, respectively (top row in inches, bottom row in percent change).




Note: The left-hand column illustrates the historical values (top row and bottom row are identical), while the middle and right-hand columns illustrate change (top row in inches, bottom row in percent change) from 1970-1999 values to the 2030s and 2070s, respectively.

**Figure 3-37. Comparison of change in mean annual recharge to groundwater for the central tendency climate scenarios, using groupings of GCMs from CMIP5**

## Outputs

The Upper Klamath Basin MODFLOW model was implemented using projected inputs as previously described. For the purpose of the Klamath River Basin water supply assessment, historical pumping was used to explore the effects of climate change alone on the groundwater balance.

The MODFLOW model computes an overall groundwater budget on a seasonal timestep. Table 3-10 summarizes projected mean changes in the primary output components of the budget for the central tendency HDe scenario. These components consist of groundwater discharge to drains, evapotranspiration, and groundwater discharge to streams. Drains include surface water conveyances such as constructed canals and ditches and natural springs. Units for discharge to drains may be described as cubic feet per second (cfs) per grid cell, where discharge (in cfs) is the mean computed over the simulation period (water years 1970–1999) and across all MODFLOW grid cells designated as drains. Basin-wide changes in groundwater discharge to drains are projected to increase by less than two percent for both the 2030s and 2070s. Considering four central tendency scenarios (CMIP3 2030s and 2070s as well as CMIP5 2030s and 2070s), the greatest increase in discharge to drains is projected for the CMIP5-based 2030s scenario. The integration of projected changes in temperature and precipitation in the modeled domain (i.e., the Upper Klamath Basin) indicate greater increases for the 2030s than for the 2070s based on CMIP5.

Units for ET are inches, where ET is the mean computed over the simulation period and across all MODFLOW grid cells designated as having ET. Projected changes in mean ET indicate increases according to all central tendency projections (Table 3-10), with greater increases projected for the 2070s than for the 2030s. ET corresponds more closely with temperature than with precipitation. Projections of annual temperature (Table 3-5) indicate similar projected increases in the central tendency for the 2030s (CMIP3 and CMIP5) and similar yet greater increases for the 2070s.

Discharge to streams is presented in units similar to discharge to drains, namely mean discharge (cfs) per MODFLOW grid cell designated as stream. Seasonal mean discharge to streams is projected to increase, with the greatest increases projected for the CMIP5 2030s and the CMIP3 2070s scenarios (Table 3-10).

**Table 3-10. Average percent change in mean groundwater balance variables**

| Central Tendency Projections | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| GW Losses to Drains | +0.4% | +1.8% | +1.2% | +1.3% |
| GW Losses to ET | +4.1% | +5.2% | +7.3% | +6.4% |
| GW Losses to Streams | +2.0% | +5.2% | +5.3% | +4.8% |

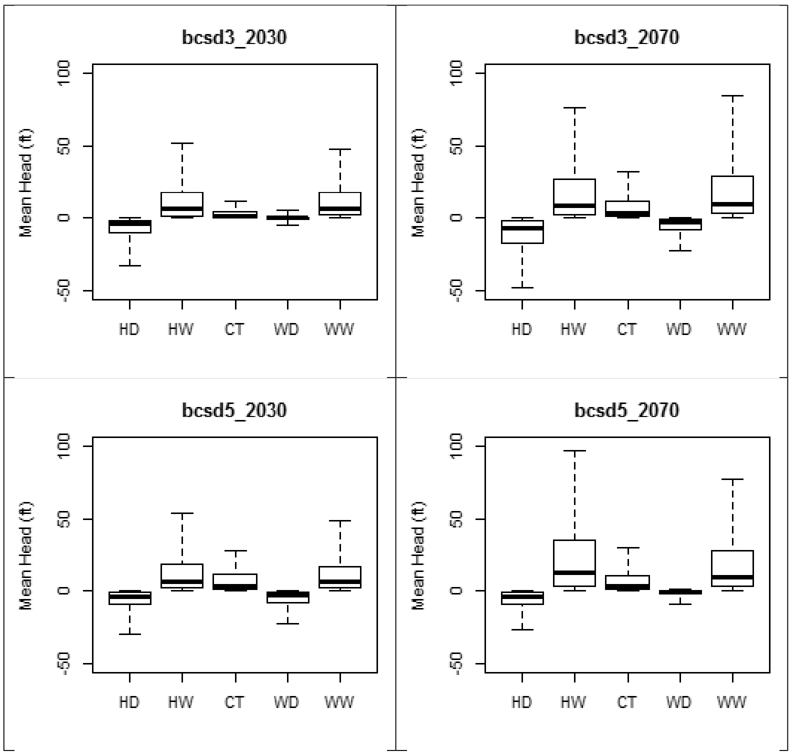
In addition to projected changes in the overall groundwater budget, projected changes in groundwater head for the three vertical layers represented in the MODFLOW model were evaluated as part of the water supply assessment. Groundwater head corresponds with the elevation of the water table. Projected changes in mean groundwater head for the central tendency scenario (2030s CMIP3 and CMIP5 as well as 2070s CMIP3 and CMIP5) are summarized in Table 3-11. Groundwater head is projected to increase by between 1.8 and 7.8 feet for the 2030s (central tendency) and between 4.4 and 8.2 feet for the 2070s.

**Table 3-11. Average change in groundwater head due to MODFLOW simulations based on projected changes in all variables for the central tendency projection**

| Central Tendency Projected Change (in feet) | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| Change in Head, All, Layer 1 | 3.1 | 7.8 | 8.2 | 7.7 |
| Change in Head, All, Layer 2 | 2.0 | 5.0 | 4.9 | 4.8 |
| Change in Head, All, Layer 3 | 1.8 | 4.6 | 4.4 | 4.3 |

Note: “All” variables include recharge and max ET

Figure 3-38 focuses on layer 1 and shows how projected changes in groundwater head (in feet) for the central tendency compare with other HDe scenarios. Layer 1 is presented because it has the greatest sensitivity to projected climate changes. The wetter scenarios (HW and WW) generally indicate larger increases in groundwater head than the central tendency, while the drier scenarios (HD and WD) indicate smaller increases or even decreases in groundwater head, depending on the type of projection (CMIP3 or CMIP5) and time horizon (2030s or 2070s).

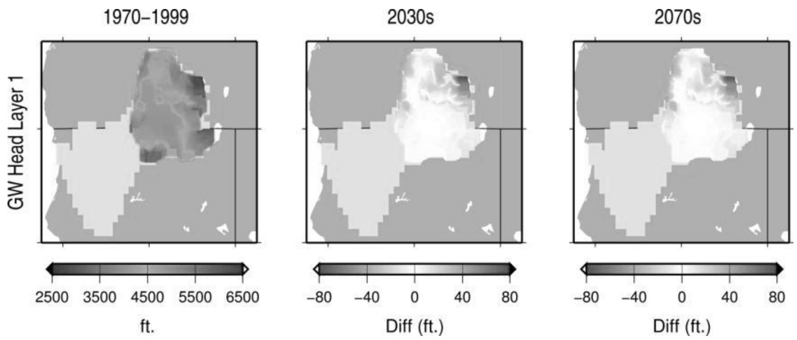



Notes:

1. The heavy black line represents median of values across the roughly 32,000 cells within the MODFLOW model domain (MODFLOW spatial resolution), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW=– hot wet, HD = hot dry.

**Figure 3-38. Summary of difference in projected mean groundwater head for MODFLOW model layer 1 for 2030s and 2070s time horizons compared with the historical baseline period of 1970–1999 water years**

Projected changes in groundwater head for layer 1 for the CMIP5-based central tendency scenario are presented spatially in Figure 3-39. The left column illustrates historical mean seasonal groundwater head over the simulation period 1970–1999 (water years), while the middle and right columns illustrate projected changes in feet for the 2030s and 2070s, respectively. The figure shows that projected changes may result in a substantial depth of water, up to about 50 feet in the northeast portion of the basin. As a point of reference, land surface elevations in the Upper Klamath Basin modeled domain range from 2,500 feet to 8,500 feet.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate change (in feet) from 1970–1999 values to the 2030s and 2070s, respectively.

**Figure 3-39. Comparison of change in mean groundwater head in the uppermost layer of the MODFLOW model for the central tendency climate scenario, using groupings of GCMs from CMIP5**

The following analysis summarizes projected discharge to individual stream reaches across the Upper Klamath Basin, as defined in Figure 3-40. Projections summarized in Table 3-12 indicate increases in groundwater discharge for all designated stream reaches. Similar to projections of precipitation and recharge, CMIP5 projections for the 2030s show larger increases than CMIP3 projections, while for the 2070s CMIP3 projections show larger increases than CMIP5. Also, CMIP3 2030s projections show the greatest change overall (even greater than for the 2070s). As previously discussed, the relative differences between scenarios are a result of the process of grouping GCM projections as part of the HDe approach. The smallest projected increases are for Lost River and Wood River reaches, while the largest projected increases are for Sycan and Sprague River reaches.

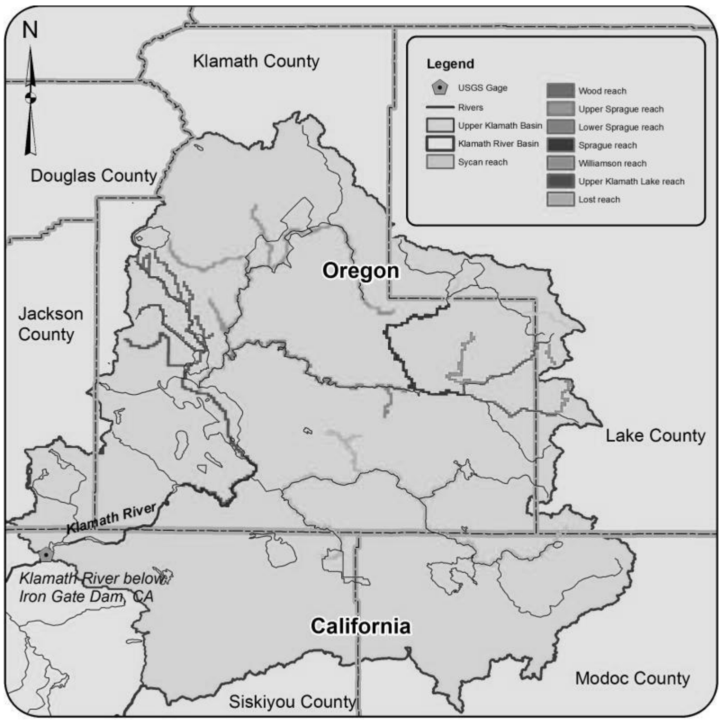



**Figure 3-40. Overview map of MODFLOW stream reaches analyzed as part of the Klamath River Basin Study water supply assessment**

**Table 3-12. Average percent change in groundwater losses to streams over the simulation period for central tendency projections**

| Central Tendency Projections (Percent Change) | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| Lost River | +0.7% | +2.6% | +1.9% | +1.7% |
| Lower Sprague | +2.8% | +6.5% | +6.8% | +5.3% |
| Sprague | +3.5% | +9.1% | +8.7% | +8.0% |
| Sycan | +5.2% | +13% | +13% | +12% |
| Upper Klamath Lake | +1.2% | +3.5% | +4.0% | +3.6% |
| Upper Sprague | +2.6% | +7.4% | +6.8% | +6.7% |
| Williamson | +2.7% | +6.9% | +7.6% | +6.2% |
| Wood River | +1.0% | +3.0% | +3.6% | +3.1% |

### *3.7.4.2 Scott Valley*

The groundwater screening tools developed for the Scott and Shasta Valleys allow for the evaluation of projected changes in mean groundwater elevation. Figure 3-41 illustrates projected changes in monthly groundwater elevations for the two future time periods based on CMIP5 (panels a and b). Individual boxes in each panel represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. The historical simulation period is calendar years 1980–1999, while the future simulation period is effectively a 50-year period that represents the characteristics of the chosen future time horizon (2030s or 2070s, in this case). Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period in the absence of any changes in groundwater use beyond that associated with population growth. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases.

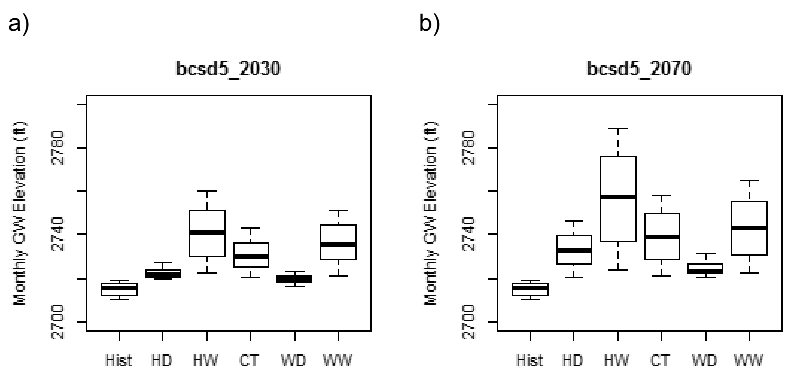



**Figure 3-41. Summary of projected groundwater elevation for Scott Valley**

The central tendency projections fall in between, with a median projection of a 15 foot increase in groundwater elevation by the 2030s and a 23 foot increase by the 2070s. To provide some context, the Scott and Shasta Valleys experienced fluctuations in annual groundwater elevation of about 20 feet over the period 1980–1999. Projected increases in groundwater elevation in the Scott Valley correspond with projected increases in precipitation in the watershed. Projected increases in actual ET computed by the VIC surface water hydrologic model (based on an assumption of natural vegetation) are not great enough to offset the projected increases in precipitation, resulting in greater potential for groundwater recharge.

It is notable that the HW scenario based on CMIP5 indicates a greater increase in groundwater elevation than the cooler (WW) scenario. One would expect the HW scenario to have a smaller increase in groundwater elevation due to greater ET losses. However, the HW scenario may actually be wetter than the WW scenario, which may compensate for any additional ET losses due to higher temperatures.

CMIP3- and CMIP5-based projections are similar for the two future time horizons; however CMIP5-based projections generally result in greater increases in groundwater elevation, corresponding with greater increases in precipitation compared with CMIP3. Individual scenarios may also differ to due to the automated selection process for individual GCM projections within a quadrant (refer to Section 3.5.1.1, Climate Projections for additional explanation of the projection selection procedure).

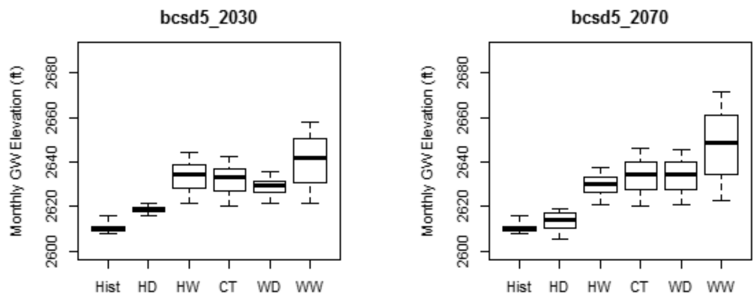
#### *3.7.4.3 Shasta Valley*

Projected changes in monthly groundwater elevation for the Shasta Valley are summarized in Figure 3-42 (panels a and b) for the two future time periods based on CMIP5. Box plots are similar to those in Figures 3-41 and represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations in the Shasta Valley.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. The central tendency scenarios based on CMIP5 indicate about a 24-foot increase in groundwater elevation for the 2030s and a 25-foot increase for the 2070s, compared with the historical baseline. To provide context, historical Shasta Valley groundwater elevations fluctuated approximately 20 feet over the historical simulation period. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases. The WW scenario indicates the greatest projected change, likely because ET rates are probably lower than in the hotter scenarios and more water may be available for groundwater recharge.

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...






a) b)

**Figure 3-42. Summary of projected groundwater elevation for Shasta Valley**

A majority of the projections for the 2070s show greater increases in groundwater elevation than for the 2030s, with the exception of the hotter scenarios (for example, CMIP3-based HD and CMIP5-based HD and HW). A smaller increase in groundwater elevation in the 2070s compared with the 2030s, despite greater projected increases in precipitation, may be due to the combined effects of increased ET corresponding with higher temperatures.

When comparing CMIP3-based projections with CMIP5-based projections, the differences in median projections of monthly groundwater elevation are more dissimilar than would be expected. For example, the median monthly change in groundwater for the 2070s compared with the historical baseline is almost 5 feet for CMIP5 and 12 feet (more than double) for CMIP3. This example illustrates the importance of considering a wide range of climate scenarios (including both CMIP3 and CMIP5) in the analysis of water supply impacts.

## Future Availability – Scott and Shasta Valley Groundwater

Projected monthly groundwater elevations in the Scott and Shasta Valley alluvial aquifers (as defined by CDWR Bulletin 118) for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. However, the projected changes are within or close to the historical fluctuations in groundwater elevation in the two basins (on the order of 20 feet for both basins).

## 3.8 External Factors Affecting Water Supply

In addition to detailed analysis of historical and projected surface and groundwater supplies, this chapter also discusses existing knowledge and research regarding historical and projected sea level rise and wildfire risk. We acknowledge that these phenomena have and may continue to change due to projected changes in climate, and they are important considerations when analyzing water supplies in the Klamath River Basin. Sea level rise poses many risks to the coastal landscape and population. Projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things.

### 3.8.1 Projected Sea Level Rise

A warming climate causes global sea level to rise by two primary mechanisms: increasing ocean volume due to expanding sea water associated with warming, and the melting of land ice. Other, more regional phenomena impact the extent of sea level rise off the coast of Oregon and California. For instance, climate patterns such as El Niño and the PDO affect winds and ocean circulation, raising local sea level during warm phases (e.g., El Niño) and lowering sea level during cool phases (e.g., La Niña). Large El Niño events can raise coastal sea levels by 4 to 12 inches for several winter months (NRC, 2012). Tectonics may also affect regional sea levels. In some regions, tectonics may cause the land surface to rise in some regions and fall in others, indicating rising and falling sea levels, respectively. For example, records from 12 west coast tide gages indicate local variability in sea-level change along the coast, although most of the gages north of Cape Mendocino, California, show that relative sea level has been falling over the past 6–10 decades (NRC, 2012). Sea level projections due to climate change are confounded by changes due to naturally occurring phenomena described above.

This section summarizes the findings from three primary documents describing the impacts of climate change on sea level rise in the coastal region of the Klamath River Basin. The first is a 2012 assessment by the National Research Council of best available science with respect to sea level rise in California, Oregon, and Washington. The second document is the Public Draft Report of the most recent National Climate Assessment, which was published in 2013. At the completion of the Klamath River Basin Study water supply assessment, the final National Climate Assessment Report was yet not complete. The third document is the State of California Sea Level Rise Guidance Document, which was published in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team. This document provides guidance for incorporating sea-level rise projections in planning and decision-making for projects in California, but also summarizes existing knowledge on projected sea level rise.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. The assessment states that

vertical land motion from geological processes and human activities, estimated by global positioning system (GPS) measurements, show that much of the western coast north of Cape Mendocino (including the coastal region of the Klamath River Basin) is rising about 0.06–0.1 inches per year (NRC, 2012). Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides (Garfin et al., 2014). Rising land masses may exacerbate the issue of coastal flooding and erosion.

Projections for the Washington, Oregon, and California coasts north of Cape Mendocino indicate that sea level is projected to change between -2 inches (sea-level fall) and +9 inches by 2030, between -1 inch and +19 inches by 2050, and 4–56 inches by 2100 (NRC, 2012). Sea level is likely to rise at a greater rate during the 21st century than it has in the 20th century. Figure 3-43 illustrates projected sea level rise (in centimeters) along the entire west coast of the U. S.

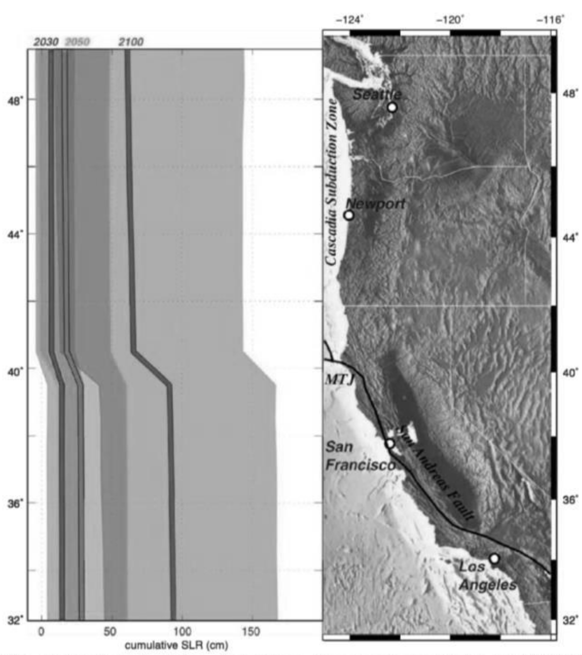



FIGURE S.1 Projected sea-level rise off California, Oregon, and Washington for 2030 (blue), 2050 (green), and 2100 (pink), relative to 2000, as a function of latitude. Solid lines are the projections, and shaded areas are the ranges. Ranges overlap, as indicated by the brown shading (low end of 2100 range and high end of 2050 range) and blue-green shading (low end of 2050 range and high end of 2030 range). MTJ = Mendocino Triple Junction, where the San Andreas Fault meets the Cascadia Subduction Zone.

*Source: NRC, 2012, Figure S.1*

**Figure 3-43. Projected sea level rise along the west coast of the United States**

Risks associated with projected sea level rise include the increased risk of coastal flooding, storm surge inundation, coastal erosion and shoreline retreat, and wetland loss. NRC (2012) highlights the significant risk posed to the region north of Cape Mendocino from a large earthquake (magnitude greater than 8) along the Cascadia Subduction Zone, which could cause significant land subsidence resulting in instantaneous sea-level rise as well as a tsunami. In addition, many coastal wetlands, tidal flats, and beaches will likely decline in quality and extent as a result of sea level rise.

### 3.8.2 Projected Wildfire Risk

The sections of the Public Draft of the most recent National Climate Assessment most relevant to the area of this study (Garfin et al., 2013 for the southwest U.S.; Mote et al., 2014 for the northwest U.S.) summarize past and projected trends in wildfire risk along the west coast, including the greater region surrounding the Klamath River Basin. Increased warming, due to climate change, and drought have increased wildfires and impacts to people and ecosystems in the Southwest, including California. A number of studies have documented increases in wildfire fire season duration and fire frequency and project increases in the probability of large wildfires. Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Mote et al., 2013). Between 1970 and 2003, warmer and drier conditions increased the burned area in western U.S. mid-elevation conifer forests by 650 percent (Westerling et al., 2006). Models project up to 74 percent more fires in California in the future (Westerling et al., 2012).

Some of the causes of increased wildfire risk include projected decreases in late summer stream flows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. Potential increases in water deficits may increase tree stress and mortality, tree vulnerability to insects, and fuel flammability (Mote et al., 2013). Also, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential (Interior and CDFG, 2011).

## 3.9 Uncertainties Associated with Impacts Assessment Approach

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study water supply assessment, including the use of climate change scenarios as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of GCM climate projections and applied downscaling techniques is provided by Reclamation (2011d). The nature of these uncertainties is only briefly described below.

### 3.9.1 Global Climate Projections, Modeling, and Downscaling

The climate projections considered in this report represent a range of future greenhouse emission pathways (Reclamation, 2011d); however, uncertainties associated with estimating these pathways, including those introduced by assumptions of global growth and land use, are not explored in this analysis. Additional uncertainty is associated with feedbacks such as the influence of human-produced aerosols in the atmosphere.

GCMs themselves have associated uncertainty with respect to their initial conditions and representation of physical processes. Model simulations may have quite different realizations of longer timescale climate patterns. Regarding representation of physical processes, the most recent generation of GCM simulations (based on CMIP5) incorporate, in many cases, improved understanding of the climate system. By using both CMIP3- and CMIP5-based projections as part of the Klamath River Basin Study water supply assessment, we may evaluate the differences in results based on a wider range of model constructs. GCMs may have biases toward being too wet, too dry, too warm, or too cool, and these should be identified and accounted for in climate change impacts studies (Reclamation, 2011d). For example, Bindoff et al. (2013) acknowledge that the observed global mean surface temperature has shown a much smaller increasing linear trend over 1998-2012 than the suite of CMIP5 models. However, there is very high confidence that the CMIP5 models show long-term trends consistent with observations, despite the disagreement over this period. Due to internal climate variability, in any given 15-year period the observed trend in the global mean surface temperature sometimes lies near one end of a model ensemble.

Generally, to account for potential inconsistencies between simulated climate and observed conditions, projections are bias corrected. The term bias correction refers to the use of a statistical procedure to adjust global climate model projections to remove differences between simulated and observed climate conditions computed over a common historical time period. This method assumes that biases are systematic and their distributions over the historical time period would be similar to a future time period. The IPCC identifies primary causes of bias in global climate model simulations to be related to the coarse resolution of global climate models and the corresponding inability to resolve important stationary features such as land surface topography and land-water interfaces along coastlines and the use of simplified parameterizations to represent physical processes that occur at too small a scale or are too complex to be represented physically. Model biases can significantly affect impact studies that use climate projections to evaluate hydrologic and ecosystem response to potential changes in climate. As a result, bias correction is often required before global climate model outputs can be used as inputs to other types of models.

Uncertainties are also associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. The Klamath River Basin Study utilizes statistically downscaled climate projections to

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derive HDe climate scenarios. Although these types of scenarios have been used to support numerous water resources impacts studies, uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies, such as statistical downscaling, require historical reference information use on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably would change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

### 3.9.2 Watershed Vegetation Changes under Climate Change

In Reclamation (2011d) and related literature sources cited, the chosen approach for assessing hydrologic effects under projected climate changes is to use a surface water hydrologic model that computes hydrologic conditions, given changes in weather, while holding other watershed features constant. Vegetation features might be expected to change as climate changes, and that, in turn, would affect runoff through changes to evapotranspiration and infiltration processes.

### 3.9.3 Quality of Hydrologic Model Used to Assess Hydrologic Effects

In Reclamation (2011d) and most of the cited literature sources, the chosen approach for assessing surface water hydrologic effects has typically involved using surface water hydrologic models, which may not represent key hydrologic processes related to groundwater and/or large water bodies. Reclamation (2011d) discusses these limitations, and they are illustrated in Section 3.3.2, Historical Surface Water Availability – Approach, which shows how the VIC model imperfectly reproduces historical runoff conditions. Some of these imperfections could be reduced through refined redevelopment, or calibration, of the model. Another approach for exploring the uncertainty associated with the VIC hydrologic model, which was not taken in this study, would be to apply additional surface water hydrology models and compare results across simulations.

In the case the Klamath River Basin, refinement of VIC model calibration is challenging due to the lack of available naturalized flow datasets. Reclamation (2005) showed the difficulty in developing naturalized flows in such a complex watershed. Additional efforts may be invested in this area; however, focusing on a change of projected future conditions relative to historical conditions is a scientifically defensible approach taken in numerous climate change impacts

studies, and is the approach taken for the Klamath River Basin Study water supply assessment.

### 3.9.4 Quality of Groundwater Models Used to Assess Groundwater Effects

Groundwater modeling in general is extremely challenging due to the complexity of most groundwater systems (the Klamath River Basin included) coupled with a general lack of sufficient data to characterize groundwater basins in great detail. The USGS has made great efforts in collecting data and developing a fine scale finite-difference MODFLOW model for the Upper Klamath Basin (Gannett et al., 2012). Despite the high level of effort taken in this study, significant uncertainties still remain about the adequacy of the model to characterize detailed groundwater dynamics in the basin. Gannett et al. (2012) discuss possible reasons for differences between observed and simulated groundwater elevations in parts of the basin, including lack of accurate information on rates and locations of pumping, and coarse vertical discretization of the model relative to the gradients of groundwater flow. Nonetheless, we may assume that historical biases in the MODFLOW model may carry through to the future. As such, we may evaluate the relative change of projected groundwater elevations and discharge compared with the historical simulation.

The Scott and Shasta Valleys have greater issues of data availability for characterizing the groundwater systems than the Upper Klamath Basin, where more resources have been invested in monitoring and evaluating the groundwater system. Monitoring wells are few and the monitoring data available for those wells is sparse, generally consisting of two or so measurements per year. In addition, CDWR Bulletin 118 was used to define groundwater basins in these regions, and these likely do not represent the complexity of groundwater aquifers that exist there. Development of groundwater models for these basins using this information poses a challenge. Furthermore, the size of these groundwater basins is much smaller than the Upper Klamath Basin, making the coarse spatial resolution of groundwater model inputs (such as precipitation, temperature, and gridded runoff) less relevant at the scale of these sub-basins. Due to these high levels of uncertainty, a statistical modeling approach was taken to simulate groundwater elevations in the Scott and Shasta Valleys. A simpler approach may be justified when uncertainty associated with input data is high. Still, the statistical models may be used to evaluate the relative change of projected groundwater elevations compared with estimated historical conditions.

### 3.9.5 Climate Projections from CMIP3 and CMIP5

The above discussions of uncertainty related to climate forcings and downscaling techniques are based on analysis of projections from CMIP3. The models and scenarios of emissions used in CMIP5 differ in several ways from those used in CMIP3. First, model resolution has generally increased by a factor of 2 (i.e., CMIP5 models have, on average, twice the number of grid cells representing the atmosphere than CMIP3 models). Second, although many of the models used in CMIP5 are similar in structure to those used in CMIP3, many incorporate updated

physics and added, or improved, individual process representation. Some of the models used in CMIP5 reflect a fundamental advancement in model structure by incorporating biogeochemical cycling; this new class of models is referred to as Earth System Models. Third, there are notable differences in precipitation for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP3 projections): namely, that these regions will become drier, resulting in reduced runoff. It is important to recognize that while CMIP5 offers new information, more work is required to better understand CMIP5 and its differences compared to CMIP3. In some regions, model resolution is likely the leading factor in these differences. In the North American Monsoon region, for example, the higher resolution of CMIP5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP3 models.

The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. While CMIP5 projections may inform future analyses, many completed and ongoing studies are informed by CMIP3 projections that were selected as the best information available at the time of the study. Even though CMIP5 provides the latest available suite of climate projections, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 projections. Current state of practice relies on one or both suites of climate projections for use in impacts studies.

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# Chapter 4
# Klamath River Basin Study
# Assessment of Current and Future Water Demands

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# Chapter 4 Assessment of Current and Future Water Demands

## 4.1 Introduction

Changes in water demands in the Klamath River Basin over the next 50 years are uncertain, and will depend on a number of socioeconomic and other factors. The Klamath River Basin Study aims to assess the impacts of climate change on water supply and demand in the watershed from its headwaters to the mouth, and to identify current and projected water supply shortages. This chapter of the Klamath River Basin Study report quantifies current water demand and projected future water demand in a changing climate. Future demand projections are meant to be sufficiently broad to capture the plausible ranges of uncertainty. Projected water demands are evaluated along with the projected supply conditions in Chapter 3 as part of a system reliability analysis to identify potential water supply shortages in the Klamath River Basin, which is presented in Chapter 5. The system reliability analysis, presented in Chapter 6, identifies any potential shortfalls between demand and supply, as well as potential strategies to plan for and reduce gaps.

Statistically downscaled climate projections from general circulation models (GCMs) inform both the demand and supply analyses. As discussed in Chapter 3, two sets of downscaled GCM output were used in the analyses: Coupled Model Intercomparison Project Phase 3 (CMIP3) and Coupled Model Intercomparison Project Phase 5 (CMIP5). The main components of the Klamath River Basin Study and their interaction with developed climate change scenarios are shown in Figure 4-1. The ensemble hybrid delta (HDe) period change method (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d) described in Chapter 3 was used to assess the impacts of climate change on demands. The future periods used for the Klamath River Basin Study are the 2030s and 2070s (represented as the mean over 2020–2049 and 2060–2089, respectively) and the historical baseline period used for the analyses is 1950–1999.

Some of the analyses described in this chapter are based on previous work done as part of Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). WWCRA is a component of the Department of the Interior WaterSMART Program that was implemented to meet requirements of the Secure Water Act (Public Law 111-11, Sections 9501-9510).[6]

[6] http://www.usbr.gov/WaterSMART/wcra/index.html

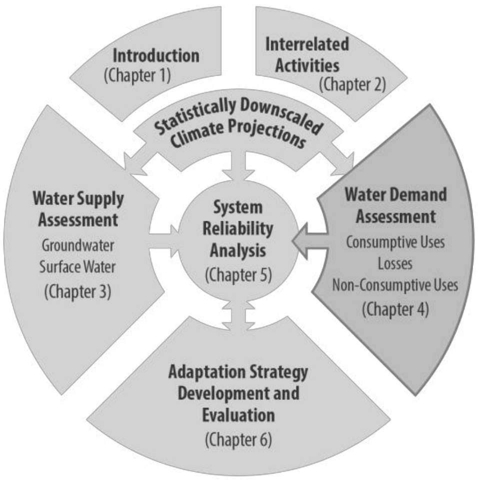


**Figure 4-1. Overall approach of Klamath River Basin Study, highlighting Chapter 4**

### 4.1.1 Description of Water Demands

Water demands are typically associated with one or more water uses that can be consumptive or non-consumptive. Consumptive water use results in a loss of water from the supply system, often associated with human activities. Examples of consumptive uses include manufacturing, agriculture, and food preparation where water is not returned to the supply system. Evaporation from water bodies such as reservoirs is another type of consumptive use that is more typically considered a loss. Non-consumptive uses are those which do not deplete the water supply. There are many types of non-consumptive uses; significant examples relevant to this study include hydropower generation, environmental resources, recreation, and aquaculture. Municipal and industrial (M&I) and rural domestic demands are typically comprised of both non-consumptive and consumptive uses. Another significant demand category relevant to the study is tribal demands, which are also comprised of both consumptive and non-consumptive uses.

## Definition of Terms

**Demand** – Water needed to meet identified uses.

**Consumptive Use** – Water use resulting in a loss of available water supply, often associated with human activities.

**Loss** – Reduction of available water supply due to evaporation and operation inefficiencies.

**Non-Consumptive Use** – Water use not resulting in reduction of available water supply.

The focus of the Klamath River Basin Study is the assessment of current and future demands with respect to consumptive uses (both human-influenced and natural) and losses. Non-consumptive demands are either discussed qualitatively in this chapter or are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6.

### 4.1.2 Previous Studies

Many previous studies have quantified various types of water demand in all or part of the Klamath River Basin. Table 4-1 identifies the references that were reviewed in development of the water demands assessment. In the case of agricultural irrigation and reservoir evaporation, we utilized methods described by Reclamation (2014) in order to maintain consistency with approaches used in other western U.S. watersheds.

The following sections discuss current and future water demands, and detail how previous studies were used and whether the analysis was quantitative or qualitative.

**Table 4-1. Summary of demand categories and related previous studies**

| Demand Categories | Primary Information Source(s) | Domain |
|---|---|---|
| **Human Influenced Consumptive Uses** | | |
| Agricultural irrigation | Reclamation WWCRA (2014) | Western U.S. |
| | | U.S. Counties |
| | HDR (2008) | Oregon |
| | CDWR (2009) | California |
| | Cuenca (1992) | Upper Klamath Basin (Oregon) |
| | Gannett et al. (2007) | Upper Klamath Basin |
| | Reclamation (2005b) | Klamath Project area |
| Municipal & Industrial | CDM (2010) | Klamath Falls, OR |
| | SHN (2004) | Hayfork, CA |
| | Pace (2011) | Weaverville, CA |
| | Pace (2004) | Weed, CA |
| | Tully and Young (2010) and Pace (2006) | Yreka, CA |
| | The USGS Water Use Program (http://water.usgs.gov/watuse/; Kenny et al., 2009) | U.S. Counties |
| | HDR (2008) | Oregon |
| | CDWR (2009) | California |
| Rural Domestic | USGS Water Use Program | U.S. Counties |
| Tribal | Interior and CDFG (2012) | |

**Table 4-1. Summary of demand categories and related previous studies**

| Demand Categories | Primary Information Source(s) | Domain |
|---|---|---|
| **Other Consumptive Uses and Losses** | | |
| Wetlands | Stannard et al. (2013) | Upper Klamath Basin |
| | Mayer and Thomasson (2004) | Lower Klamath NWR |
| | Bidlake (2002) | Tule Lake NWR |
| Evaporation from lakes and reservoirs | Reclamation WWCRA (2014) | Western U.S. |
| | Bidlake (2000), Bidlake and Payne (1998), Janssen and Cummings (2007), and Stannard et al. (2013) | |
| **Non-Consumptive Uses** | | |
| Environmental Resources | See Section 4.2.3.2, Environmental | |
| Hydropower | See Section 4.2.3.3, Hydropower | |
| Recreation | See Section 4.2.3.1, Recreation | |
| Aquaculture | See 4.2.3.4, Aquaculture | |

## 4.2 Current Demands

Historical and current consumptive water uses and losses were quantified through findings from previous studies and model simulations and evaluated in order to compare with potential future changes due to climate change. Non-consumptive uses are briefly discussed; however, these uses are quantified in the modeling supporting the system reliability analysis in Chapter 5. Identified non-consumptive needs are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6. The current demands considered in this chapter are listed in Table 4-2 along with the sources or models used to provide an estimate for the Klamath River Basin Study. Each of the demands evaluated in this chapter, and the associated estimates used, are discussed in the sections that follow.

**Current Human Influenced Consumptive Uses**

Based on analyses supporting the Klamath River Basin Study, total consumptive water demand for human uses in the basin is about 800,000 acre-feet/year and about 98 percent of the total human influenced demand is for agricultural irrigation.

### 4.2.1 Human Influenced Consumptive Uses

Consumptive uses for human needs in the Klamath River Basin Study demands assessment have been quantified using a variety of existing sources as well as

model simulations. Table 4-2 summarizes the categories for which demands have been quantified, showing primary sources of data and models used.

One existing source of consumptive use information, which was used in conjunction with other sources described later, is the countywide USGS Water Use Program data. This is arguably the most comprehensive source of existing water use information for the study area (including both consumptive and non-consumptive uses). The most current data available are typically for 2005 and 2010, but more recent data were available in a few cases.

## Current Human Influenced Consumptive Use Estimate Sources

Human influenced consumptive use estimates are based in part on USGS data, but this study uses WWCRA based model simulations for agricultural demands

**Table 4-2. Summary of demand categories evaluated by the Klamath River Basin Study Assessment of Current and Future Water Demands and data and methods used**

| Demand Categories | Data Sources Used | Methods Used |
|---|---|---|
| **Human Influenced Consumptive Uses** | | |
| Agricultural irrigation | Reclamation WWCRA (2014) | ET Demands Model (further described in corresponding section) |
| Municipal & industrial | Municipal water plans and USGS Water Use Program (see references in Table 4-1) | Statistical models and historical information |
| Rural domestic | USGS Water Use Program | Statistical models and historical information |
| Tribal | Addressed as part of agricultural, M&I, and Rural Domestic demand categories | |
| **Other Consumptive Uses and Losses** | | |
| Wetlands | Stannard et al. (2013) | ET Demands Model and empirical relationships |
| Evaporation from lakes and reservoirs | Reclamation WWCRA (2014) | Complementary Relationship Lake Evaporation (CRLE) model |

Included in Table 4-3 are 2005 USGS usage estimates for Siskiyou and Trinity Counties in California, Klamath County, Oregon, and the portion of Modoc County, California within the Klamath River Basin.[7] The total basin demand is approximately 1.2 million acre-feet per year (AFY). Note that Table 4-3 values are not all-inclusive since Del Norte and Humboldt Counties in the California portion of the basin are not included. Estimates for these counties are not

[7] http://water. usgs.gov/watuse/

included since only a very small portion of their water demands (estimated between 1 and 2 percent) occur within the basin. The in-basin demands for these counties are discussed later under the specific demand category discussions. Also note that the USGS data do not include reservoir evaporation. Additionally, the uses reported in Table 4-3 include both consumptive and non-consumptive components of these uses. For example, municipal and industrial (M&I) use includes water that eventually returns to the river system via a wastewater treatment plant.

**Table 4-3. Summary of USGS 2005 Water Use Program estimates for the Klamath River Basin**

| Water Use Category (note: includes both consumptive and non-consumptive uses) | 2005 Use (AFY) |
|---|---|
| Surface water irrigation | 717,154 |
| Groundwater irrigation | 433,164 |
| Municipal and industrial | 18,204 |
| Rural domestic | 11,255 |
| Livestock | 2,903 |
| Mining and industrial/commercial | 2,868 |
| **Total (human influenced uses)** | **1,185,548** |

*Source: USGS Water Use Program*

The Klamath River Basin Study estimates of current human influenced consumptive uses in the watershed are based in part on the USGS Water Use Program data summarized above. However, in the case of agricultural irrigation demand (surface and groundwater), this study utilizes model simulations of agricultural water requirements following the approach of Reclamation's West Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). In the case of M&I and rural domestic water uses, more current (2010) estimates were made based on historical population trends. Also, the study focuses only on the consumptive portion of these demands, which is assumed to be 40 percent for both M&I and rural domestic demands and comprised of landscape irrigation (refer to Section 4.2.1.2, Municipal and Industrial).

Estimated current consumptive uses (including human influenced uses, wetland ET, and reservoir evaporation losses) by the Klamath River Basin Study are summarized in Table 4-4. These are estimated basin-wide uses that are the basis for assessment of projected changes in consumptive uses and losses for the two future time periods considered in this study, the 2030s and 2070s. Respective sections of this chapter provide details behind these estimates and the associated assumptions made. Note that the estimated reported M&I and rural domestic consumptive uses (see Table 4-4) are approximately 40 percent of the values reported by the USGS Water Use Program (see Table 4-3), which supports the

assumption by the Klamath River Basin Study regarding the consumptive portion of total M&I and rural domestic demand.

**Table 4-4. Estimated current basin-wide consumptive uses and losses as computed by the Klamath River Basin Study**

| Basin Wide Consumptive Uses and Losses | Estimated Mean Annual Quantity (AFY) |
|---|---|
| Agricultural irrigation (NIWR) | 755,734 |
| Municipal and industrial | 8,801 |
| Rural domestic | 4,537 |
| **Subtotal for Human Influenced Consumptive Use** | **769,072** |
| Wetland ET | 1,089,061 |
| Reservoir and lake evaporation | 181,297 |
| **Total Consumptive Uses and Losses** | **2,039,430** |

#### *4.2.1.1 Agricultural Irrigation*

Irrigation of croplands is by far the largest human influenced consumptive use in the Klamath River Basin, 97 percent[8] according to the USGS Water Use Program estimates (which include conveyance and on-farm losses) and approximately 98 percent[9] according to the Klamath River Basin Study estimates (which do not include conveyance and on-farm losses). Agricultural irrigation use typically includes crop demands, conveyance losses, and on-farm losses. Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, these losses were not calculated in this study.

> **ET Demands Model Methodology**
>
> The model calculates historical and future daily net irrigation water requirements using the FAO-56 dual crop coefficient method with crops, temperature, precipitation, wind, and soil inputs. Solar radiation and humidity are estimated from daily minimum and maximum temperature inputs.

Crop demands are consumptive. Conveyance and on-farm losses can be consumptive or non-consumptive. Examples of non-consumptive conveyance and on-farm losses include field runoff and deep percolation, since associated water generally returns to the supply system. An example of a conveyance or on-farm loss that is

8 Computed as sum of 717,154AFY and 433,164AFY, divided by 1,185,548AFY (refer to Table 4-3).
9 Computed as subtotal for human influenced consumptive uses 755,734AFY, divided by 769,072AFY (refer to Table 4-4).

consumptive is evapotranspiration by natural vegetation on farm lands or in and around canals.

This study focuses on the crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e., effective precipitation ($P_e$). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Allen et al., 1990). Crop water demand also does not include conveyance or on-farm losses.

Current NIWR estimates have been developed for this study. A discussion of recent irrigation demand estimates is presented first, followed by a discussion of the developed NIWR estimates.

**Recent Irrigation Estimates by Others**
Estimates by others are presented as background information and for comparison to those developed in the Klamath River Basin Study. As discussed previously, the USGS estimates that total irrigation water use for the basin in 2005 was 1,150,318 AF, including 717,154 AF from surface water sources and 433,164 AF from groundwater sources (Kenny et al., 2009). These estimates include irrigation of golf courses, parks, nurseries, cemeteries, and other self-supplied landscape-watering uses. The USGS estimates also include conveyance and on-farm water losses. Detailed information on how the USGS developed the 2005 irrigation estimates is provided in Dickens et al. (2011).

> **Current Agricultural Irrigation Demand**
>
> Agricultural irrigation demands, in the form of net irrigation water requirement (NIWR), were simulated by the ET Demands model using current cropping data and average climate conditions for the period 1950–1999.

The CDWR estimates crop irrigation demands annually for the California portion of the Klamath River Basin (the Klamath Upper and Lower Planning Sub-area).[10] The CDWR estimates include NIWR and total water applied, which includes on-farm losses but not conveyance losses. The reported 2010 estimates for the California portion of the basin are 347,672 AF of NIWR and 482,504 AF total water applied (Coombe, 2013). It is estimated that approximately 62 percent of the total demand is met with surface water and 38 percent is met with groundwater sources.

The OWRD's recent Statewide Water Needs Assessment (HDR, 2008) includes a 2010 agricultural irrigation water use estimate for Klamath County, Oregon,

---

[10] http://www.water.ca.gov/landwateruse/anlwuest.cfm

which represents the approximate Oregon portion of the basin. The estimate is 730,000 AF and includes both on-farm and conveyance losses.

The sum of CDWR and OWRD estimates (1,212,504 AF) is greater than, though comparable to, the USGS estimate for total irrigation (1,150,318 AF). It is assumed the discrepancies are associated with which loss estimates were included and how they were estimated.

**Estimation of Net Irrigation Water Requirements**
Current and future NIWR estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The current or baseline irrigation water demand estimates developed for this study are based on the most recent available crop data and climate conditions during the historical baseline period 1950 through 1999. Crop types and quantities reported for 2009 were provided by the Klamath Basin Area Office for Reclamation's Klamath Project lands, and crop data for the remainder of the basin were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service as reported for 2010.[11] The 1950 through1999 climate data used are from the same published data set by Maurer et al. (2002) discussed in Chapter 3. The values used from this data set were adjusted based on historical observations from 13 weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's twelve Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basin). The HUC8 sub-basins are shown in Figure 4-2. The map also includes the estimated number of irrigated acres by HUC8 sub-basin. Point locations in the figure represent corresponding weather stations used to support the modeling effort, including those used for removing biases in the gridded meteorological dataset and those used for estimating dewpoint and windspeed across the HUC8 sub-basins. Table 4-5 provides additional details for some of these features. A full summary of weather station information is provided in Appendix C, Section 2.0. Appendix C, Section 3.0 summarizes the estimated percentage of crop acreage within each HUC8 sub-basin according to crop type.

[11] http://www.nass.usda.gov/research/Cropland/SARS1a.htm

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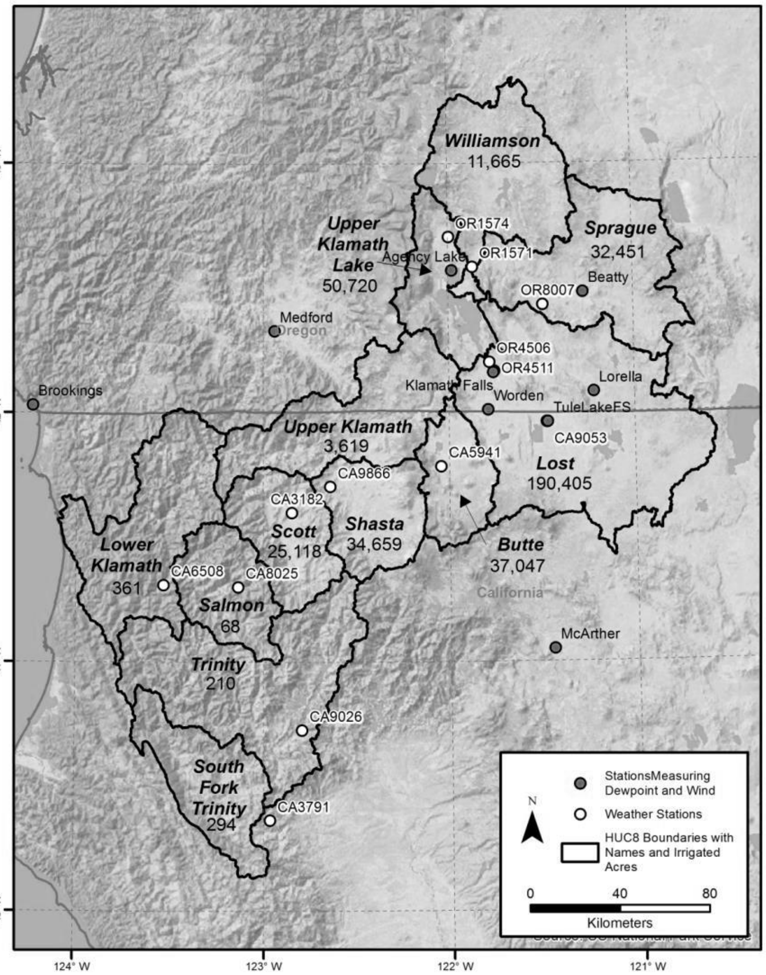


**Figure 4-2. Klamath River Basin – HUC8 Sub-basins, irrigated acres, and weather stations used to simulate baseline and projected irrigation demands**

**Table 4-5. Irrigated land totals and weather stations associated with HUC8 sub-basins**

| HUC8 Name / Number | Weather Station Name(s) | Irrigated Acres |
|---|---|---|
| Williamson / 18010201 | Chiloquin | 11,665 |
| Sprague / 18010202 | Sprague River 2 SE | 32,451 |
| Upper Klamath Lake / 18010203 | Chiloquin NW | 50,720 |
| Lost River / 18010204 | Tule Lake and Klamath Falls | 190,405 |
| Butte /18010205 | Mount Hebron | 37,047 |
| Upper Klamath / 18010206 | Klamath Falls 2 SSW | 3,619 |
| Shasta /18010207 | Yreka | 34,659 |
| Scott / 18010208 | Fort Jones | 25,118 |
| Lower Klamath / 18010209 | Orleans | 361 |
| Salmon / 18010210 | Sawyers Bar | 68 |
| Trinity / 18010211 | Trinity River Hatchery | 210 |
| South Fork Trinity / 18010212 | Harrison Gulch | 294 |
| **Total Irrigated Acres** | | **386,616** |

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI, and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET ($ET_o$) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with previous Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily $ET_o$ for each HUC8 sub-basin as a function of maximum and minimum daily air temperature ($T_{max}$ and $T_{min}$) from the 1950–1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation, and wind speed are empirically estimated as described in Reclamation (2014) per the methods recommended by ASCE (2005). Figure 4-3 shows the spatial distribution of mean daily historical baseline

temperature, precipitation, dewpoint depression,[12] and wind speed (lower right) values used in the model. The historical baseline precipitation and temperature values for each HUC8 sub-basin are included in the model results summary tables provided in Appendix C, Section 1.0. The Figure 4-3 windspeed and dewpoint depression panels include the point locations of weather stations used as the basis for estimating these values for HUC8 sub-basins (see also Figure 4-2 and Appendix C, section 2.0).

Figure 4-3 illustrates warm to cool mean annual temperatures from west-southwest to northeast, respectively, while precipitation varies from moderately high to low amounts from southwest-central to northeast, respectively. The spatial distribution of mean annual dewpoint depression clearly shows northeast areas are more arid while southwest-central areas are more humid. The spatial distribution of mean annual wind speed generally exhibits lower wind speed in west and southwest areas, with higher wind speed in the northeast portion of the basin.

Weighted average soil conditions (including allowable water content and percent clay, silt, and sand) for the irrigated lands in each HUC8 sub-basin were input to the ET Demands model. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-SCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, deep percolation from root zones, antecedent soil moisture condition, and runoff from precipitation.

[12] Dewpoint depression is equal to $T_{min}$ minus dewpoint temperature and is used to estimate vapor pressure or humidity values.
[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

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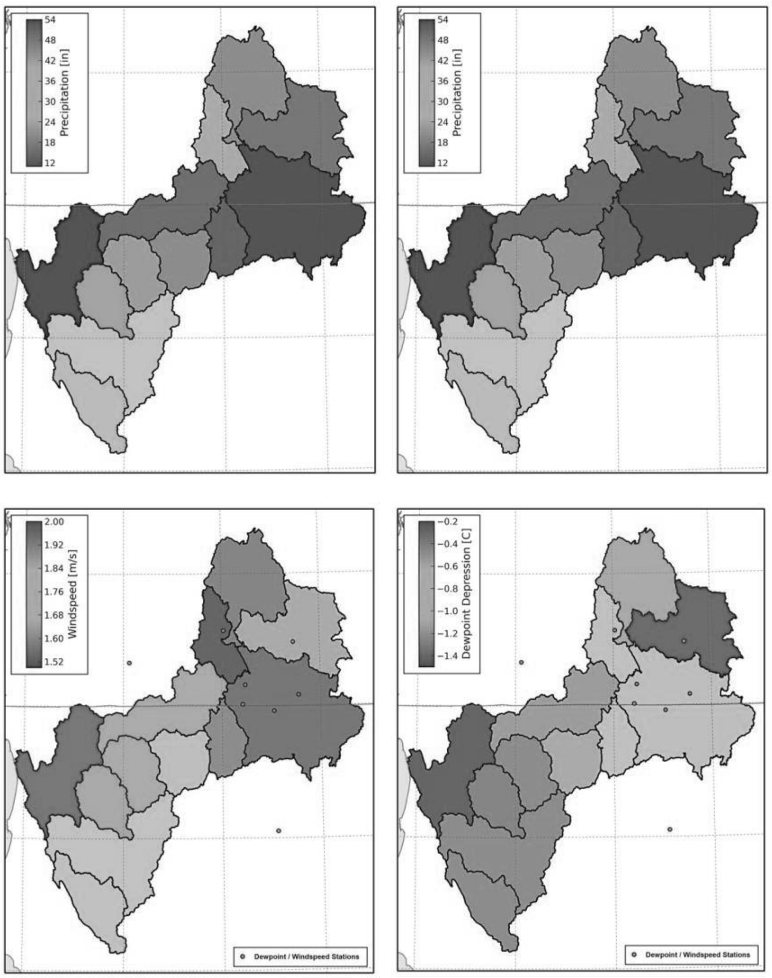


**Figure 4-3. Spatial distribution of historical baseline (1950–1999) mean annual temperature, precipitation, windspeed, and dewpoint depression**

The daily net or actual ET ($ET_c$) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. $ET_c$ for all crop types within a given HUC8 was estimated as follows:

$$ET_c = (K_s K_{cb} + K_e) ET_o$$

where $ET_o$ is the ASCE-PM grass reference ET, $K_{cb}$ is the basal crop coefficient, $K_e$ is the soil water evaporation coefficient, and $K_s$ is the stress coefficient. $K_{cb}$ and $K_e$ are dimensionless and range from 0 to 1.4. Daily $K_{cb}$ values over a season, commonly referred to as the crop coefficient curve, represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. $K_e$ is a function of the soil water balance in the upper 0.1 meter of the soil column, since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. $K_s$ ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate $K_s$. In the case of computing the $ET_c$ and NIWR, $K_s$ is generally 1 but can be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass.

Values of $K_{cb}$ for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in the ET Demands model by each crop specific $K_{cb}$ as a function of air temperature. This is expressed in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of $K_{cb}$ gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the $K_{cb}$ value is generally constant or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the $K_{cb}$ value reduces to simulate senescence. GDD is calculated in the ET Demands model by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in the ET Demands model by factoring in $P_e$ (NIWR = $ET_c - P_e$). $P_e$ is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture, and precipitation runoff. Soil moisture is a function of the moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity[13] and the cumulative soil moisture depletion depth amount.

The NIWR and $ET_c$ rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and $ET_c$ rates, as shown in the equation below.

$$HUC8\ subbasin\ rate\ = \sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$$

The product of the weighted average NIWR and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the $ET_o$, $ET_c$, and NIWR estimates for the entire Klamath River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated. Crop types and corresponding percentages of total crop acreage by HUC8 sub-basin are provided in Appendix C, Section 3.0.

The ET Demands model results for baseline conditions include $ET_o$, $ET_c$, NIWR rate, and NIWR volume for each HUC8 sub-basin. The annual average values for 1950–1999, which represent the historical baseline or current conditions for the purpose of this study, are summarized in Table 4-6. Graphical representations of these values are provided in Figure 4-4. Spatial distributions of $ET_o$, $ET_c$, and NIWR depth ranges from 41 to 51, 29 to 52, and 18 to 37 inches per year, respectively, with higher rates occurring in the northeast portion of the basin where growing season air temperature, solar radiation, and dewpoint depression are significantly larger relative to the southwest-central portion of the basin. NIWR volumes range from 197 AFY in the Salmon HUC8 sub-basin, where there is very little irrigated land, to 329,469 AFY in the Lost River HUC8 sub-basin where the majority of Reclamation's Klamath Project irrigated lands are located.

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

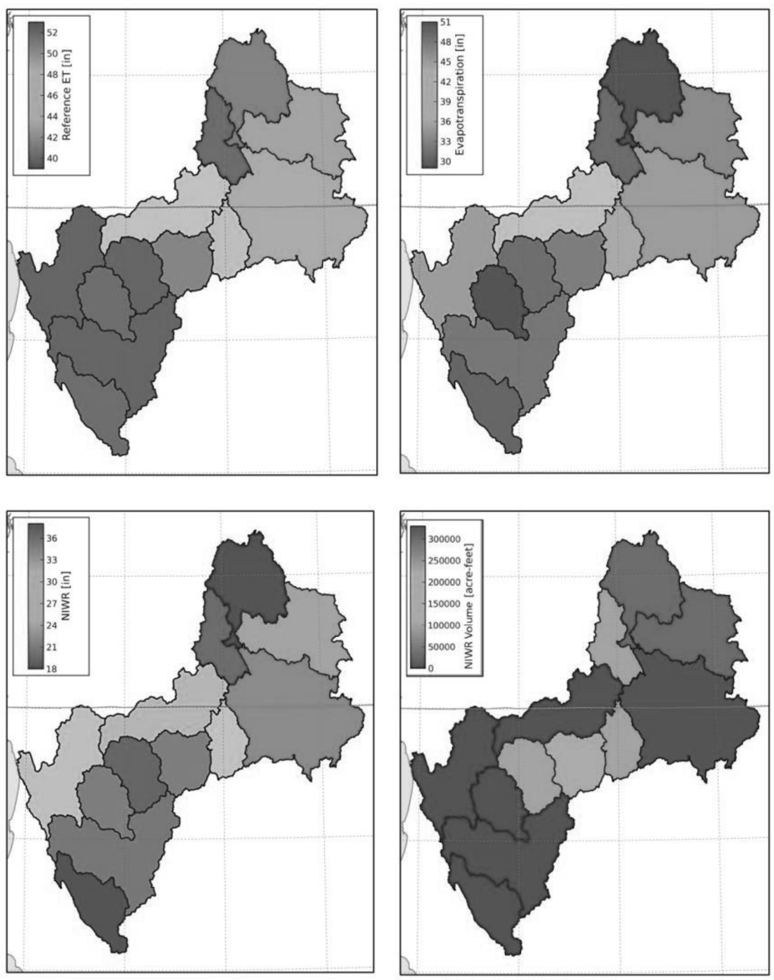


**Figure 4-4. Spatial distribution of baseline reference evapotranspiration, crop evapotranspiration, net irrigation water requirement depth, and NIWR volume**

**Table 4-6. Summary of baseline reference evapotranspiration, crop evapotranspiration, and net irrigation water requirement rates and volumes**

| HUC Sub-basin | $ET_o$ (in/year) | $ET_c$ (in/year) | NIWR Rate (in/year) | NIWR Volume (AFY) |
|---|---|---|---|---|
| Williamson | 40.8 | 29.4 | 18.0 | 17,513 |
| Sprague | 42.3 | 29.5 | 20.4 | 55,216 |
| Upper Klamath Lake | 39.9 | 30.4 | 18.7 | 79,101 |
| Lost River | 43.3 | 34.1 | 20.2 | 329,469 |
| Butte | 46.9 | 36.5 | 27.2 | 83,976 |
| Upper Klamath | 45.4 | 40.9 | 30.7 | 9,255 |
| Shasta | 50.5 | 47.9 | 35.1 | 101,460 |
| Scott | 52.3 | 49.0 | 36.8 | 77,114 |
| Lower Klamath | 52.2 | 44.6 | 29.5 | 887 |
| Salmon | 52.0 | 50.6 | 35.0 | 197 |
| Trinity | 52.3 | 48.6 | 35.9 | 628 |
| South Fork Trinity | 51.8 | 49.6 | 37.4 | 917 |
| **Averages & Total NIWR Vol.** | **47.5** | **40.9** | **28.7** | **755,734** |

Notes: ETo = reference evapotranspiration; ETc = crop evapotranspiration; NIWR = net irrigation water requirement

Table 4-7 provides a summary of the basin total NIWR from Table 4-6 and the previous irrigation estimates by USGS, CDWR, and OWRD. As discussed previously, the USGS and OWRD estimates include conveyance and application losses; the CDWR estimate includes application losses; and the USGS estimate includes irrigation demands for other uses in addition to agricultural irrigation (e.g., golf courses, parks, etc.). Depending on local conditions, significant conveyance and application losses are considered consumptive uses when providing water sources for riparian and wetland plants and sources of evaporation.

The ratio of the basin study estimate (755,734) to the USGS estimate (1,150,318) implies the overall average efficiency of the irrigation systems is approximately 66 percent, which is reasonable. The USGS estimate (1,150,318) is within 5.1 percent of the sum of the QWRD and CDWR estimates (730,000 + 482,504 = 1,212,504).

**Table 4-7. Summary of irrigation demand estimate developed for this study and previous estimates by others**

| Description | Annual Volume (AFY) |
|---|---|
| Basin total crop net irrigation water demand estimated in Klamath River Basin Study | 755,734 |
| Basin total irrigation demand from 2005 USGS Water Use Program | 1,150,318 |
| OWRD 2010 estimate of crop irrigation demand for the Oregon portion of the basin | 730,000 |
| CDWR 2010 estimate of crop irrigation demand for the California portion of the basin | 482,504 |

#### *4.2.1.2 Municipal and Industrial*

This category includes water demands that are met by public water supply systems that range in size from 15 connections[14] to many thousands of connections. The estimates are typically based on the supplier's production quantities, which include water delivered to customers plus leakage and other unaccounted for water. M&I customers include domestic households, industrial facilities, and commercial businesses.

Basin-wide total M&I use, shown in Table 4-3, is 18,204 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, which are entirely within the Klamath River Basin. Modoc, Humboldt, and Del Norte Counties each have small fractions within the Klamath River Basin. Most of the Humboldt and Del Norte County systems serve tribal communities. Note that within the California portion of the basin there is one small M&I system in Modoc County; there are four small systems in Humboldt County, and seven small systems in Del Norte County. Information on these California county systems is discussed later in this section.

Per capita total use estimates for the three counties entirely within the Klamath River Basin were calculated from the USGS data by dividing annual use by the reported population served. These estimates are summarized in Table 4-8.

**Table 4-8. Per capita total M&I water use estimates from USGS 2005 data (including consumptive and non-consumptive portions)**

| County, State | Per Capita Rates (gpcd) |
|---|---|
| Siskiyou , California | 468 |
| Trinity , California | 146 |
| Klamath , Oregon | 188 |

*Source: USGS*

[14] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.

The Siskiyou County per capita total M&I water use reported in 2005 by the USGS is much higher than for Klamath County and Trinity County. Further, review of near current total M&I use from recent planning studies for Weed and Yreka suggest this value to be outside the estimated range for the two largest municipalities in Siskiyou County.

Water plans were reviewed for the four largest municipalities in the Klamath River Basin which include Weed and Yreka in Siskiyou County, California, Weaverville in Trinity County, California, and Klamath Falls in Klamath County, Oregon. Most of the entities that provide M&I service to the smaller municipalities in Del Norte, Humboldt, and Modoc Counties were contacted for recent water use data, as they do not have municipal water plans. These include Willow Creek, Orleans, and Hoopa in Humboldt County, California, Newell in Modoc County, California, and Klamath in Del Norte County, California. Current annual water use for these municipalities is summarized in Table 4-9. Similar to uses identified by municipal water plans, these uses include both consumptive and non-consumptive components.

It should be noted that reported M&I uses typically include both consumptive and non-consumptive components. In the Klamath River Basin Study, those reported M&I uses that include both components are described as total M&I use. This study focuses only on the consumptive portion of M&I use and assumes that 40 percent of total M&I use is consumptive and is used for landscape irrigation, with the remaining 60 percent becoming wastewater effluent. In this section we distinguish between total M&I use and consumptive M&I use, where practicable.

### M&I and Rural Domestic Consumptive Use

Approximately 75 percent of the M&I demand within the Klamath River Basin is from the four largest municipalities (Klamath Falls, OR; Weed, CA; Yreka, CA; Weaverville, CA). Annual rural domestic uses represent approximately 0.4 percent of total basin demand.

Based on Mayer et al. (1999) and given that the majority of the basin's population is located in warmer-drier areas, it appears 40 percent is a reasonable average value for the basin. Mayer et al. (1999) reports the findings of a residential water use study that included 1,188 households in 12 North American cities. The reported range of outdoor use as the percentage of total use is 22 to 67 percent, with a range of 22 to 38 percent for wetter climates. Also, the U.S. Environmental Protection Agency WaterSense Program website[15] reports that one-third of U.S. residential water use is for landscape irrigation.

[15] http://www.epa.gov/WaterSense/pubs/outdoor.html

**Table 4-9. Summary of total M&I use for significant municipalities**

| Location | Annual Use (AFY) | Per Capita Demand (gpcd) | Reference |
|---|---|---|---|
| Klamath Falls, OR (Klamath County) | 9,428 (2010 est) | 167 (1998-2007est) | CDM (2010) |
| Yreka, CA (Siskiyou County) | 2,243 (2010 est) | 280-325 (2011 est) | Pace (2006), Tully and Young (2011) |
| Weed, CA (Siskiyou County) | 994 (2010 est) | NA | Pace (2004) |
| Weaverville, CA (Trinity County) | 841 (2010 est) | NA | Pace (2011) |
| **Total of Above Annual Demands** | **13,506**[16] | | |
| Newell, CA (Modoc County) | 188 | 194 | 2003 CDWR funding application (Hammond Engineering, 2001)[17] |
| Willow Creek, CA (Humboldt County) | 767 | 401 | Personal communication[18] |
| Hoopa, CA (Humboldt County) | 565 | 168 | Personal communication[19] |
| Orleans, CA (Humboldt County) | 153 (OCSD)<br>50 (OMWC) | 319 (OCSD)<br>529 (OMWC) | Personal communication[20] |
| Klamath, CA (Del Norte County) | 166 (est) | 150 (est) | Personal communication[21] |
| **Total of Above Annual Demands** | **1,889** | | |

Comparison of the total for the four large municipalities (13,506 AF) to the USGS reported 2005 M&I total (18,204 AF) indicates approximately 75 percent of the M&I demand within the majority of the basin (Klamath County, Oregon and Trinity and Siskiyou Counties in California) is from these municipalities and the other approximately 25 percent is made up by the smaller M&I systems. The Klamath River Basin Study estimates 2010 total M&I use as the sum of use in

[16] Compare with USGS total demand for Klamath, Siskiyou, and Trinity Counties of 18,204 AFY. The comparison shows that demands from the four major municipalities comprise about 75 percent of the total demand in these three counties.

[17] CDWR funding application reports an annual use of 188 AFY and a 1999 service population of 866. This yields a per capita demand rate of 194 gpcd.

[18] Mr. Lonnie Danel, Administrator (personal communication, November 8, 2013). The 2012 approximate annual use for the Willow Creek Community Service District is 767 AF. Based on the 2010 census population for Willow Creek (1,710) this use yields a per capita demand of 401 gpcd.

[19] According to Mr. Murphy Lott, Operator for Hoopa Public Utilities District, Humboldt County, California (personal communication, November 12, 2013), the 2012 total use for the District's service area was approximately 565 AFY. Based on the reported service area population of approximately 3,000, the per capita average demand is 168 gpcd.

[20] Orleans, California in Humboldt County is served by two public water systems. Debbie Mace of the Orleans Community Service District (OCSD) reports (personal communication, December 5, 2013) approximate annual total M&I usage is 153 AFY serving a population of 430. This equates to a per capita demand of 319 gpcd. Jim Slusser of the Orleans Mutual Water Company (OMWC) reports (personal communication, December 5, 2013) approximate annual total usage is 50 AFY serving a population of 85. This equates to a per capita demand of 529 gpcd.

[21] Ms. Jan Chinook (personal communication, November 12, 2013) with the Klamath, California Chamber of Commerce reports there are seven public water systems serving this community in Del Norte County. The approximate population served by these systems is reported to be 985. Three of seven operators that were successfully contacted reported their systems are not metered. Given the lack of data and the generally transient service population, per capita demand was assumed (150 gpcd) to estimate an annual total M&I use of 166 AFY.

Klamath, Siskiyou, and Trinity Counties, plus uses identified in the small municipalities of Modoc, Humboldt, and Del Norte Counties.

As stated above, an estimated 40 percent of total M&I use is for landscape irrigation. This fraction is considered 100 percent consumptive. The remaining 60 percent of the total M&I use is considered non-consumptive and is assumed to return to receiving waters as wastewater effluent. The computed basin-wide M&I consumptive use of 8,801 AFY is the baseline M&I consumptive use for the Klamath River Basin Study (see Table 4-4). The M&I uses that comprise the Klamath River Basin Study estimate of basin-wide current annual consumptive use are provided in Table 4-10.

**Table 4-10. Summary of total and consumptive M&I uses for the Klamath River Basin Study**

| Location | Annual M&I Use (AFY) |
|---|---|
| Klamath County | 9,736 |
| Siskiyou County | 7,286 |
| Trinity County | 3,093 |
| Small municipalities of Modoc, Humboldt, and Del Norte Counties | 1,889 |
| **Basin Wide Total M&I Use** | 22,004 |
| **Basin Wide Consumptive M&I Use** | 8,801 |

#### *4.2.1.3 Rural Domestic*

The estimate of basin-wide rural domestic use shown in Table 4-3 is 11,255 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, plus a portion of the reported demand for Modoc County. The Modoc County estimate was calculated as the product of the reported use for the county and the ratio of the estimated population within the basin to the total county population. It is assumed the limited number of rural domestic water users in the portions of the basin in the counties of Del Norte and Humboldt in California and Lake and Jackson in Oregon are negligible. Based on these data and excluding hydropower and lake and reservoir evaporation, annual rural domestic uses represent approximately 0.4 percent of total basin demand. Note that, similar to M&I use, the rural domestic use reported by the USGS includes both consumptive and non-consumptive components. The Klamath River Basin Study assumes that 40 percent of total rural domestic use goes to landscape irrigation and is entirely consumed. (See discussion and references to Mayer et al. (1999) and the WaterSense program[22] above under Section 4.2.1.2, Municipal and Industrial.) The remaining 60 percent of the total rural domestic use is assumed to return to receiving waters via wastewater effluent (i.e., septic systems). This study differentiates between total

[22] http://www.epa.gov/WaterSense/pubs/outdoor.html

rural domestic use, which includes both consumptive and non-consumptive components, and consumptive rural domestic use.

The total rural domestic per capita demands reported by USGS for 2005 range from 106 to 190 gpcd. The 2005 county rates and average for all but Humboldt and Del Norte counties are summarized in Table 4-11. Total rural domestic uses summarized here may be compared with total M&I demands provided in Tables 4-8 and 4-9 in terms of both per capita demands and mean annual total use volumes. Mean annual total rural domestic demands were computed based on the product of per capita demand and estimated population. Generally rural domestic demands are less than M&I demands, except for Trinity County where estimated rural domestic demand rates are higher than M&I. Table 4-9 also provides the estimated baseline consumptive rural domestic use for the Klamath River Basin Study.

**Table 4-11. Summary of 2005 county rural domestic use**

| County | Annual Rural Domestic Use (AFY) | Per Capita Demand (gpcd) |
|---|---|---|
| Siskiyou County, California | 6,621 | 190 |
| Trinity County, California | 1,040 | 158 |
| Klamath County, Oregon | 3,481 | 150 |
| Modoc County, California | 201 | 180 |
| Total Rural Domestic Use | 11,343 | |
| **Consumptive Rural Domestic Use** | **4,537** | |

#### *4.2.1.4 Tribal*

This discussion addresses the consumption portion of water demands associated with the six federally recognized tribes that inhabit the Klamath River Basin: The Klamath Tribes, Quartz Valley Indian Community, Karuk Tribe, Hoopa Valley Tribe, Yurok Tribe, and Resighini Rancheria. Members of these tribes live along different reaches of the Klamath River and in different areas of the basin. Table 4-12 provides a summary of the Klamath basin Native Americans by culture, recognized representative tribal government, and the general location of each tribe in the Klamath basin (taken from Table 1-1, North State Resources, Inc., 2012). The Klamath Tribes live in the Upper Klamath Basin and the other five tribes are in the Lower Klamath Basin.

> **Tribal Water Demands**
>
> Tribal trust resources and associated adjudicated and non-adjudicated water rights are described in this section. The needs of fish and wildlife for water are further described in Section 4.2.3.2, Environmental Resources.

Tribal water uses are unique because the associated water rights are considered trust resources.[23] Tribal domestic and industrial water uses are included in the quantification of municipal and industrial demands as well as rural domestic uses summarized above. There are also inter-relationships between tribal water demands and other non-consumptive water use categories (e.g., environmental and ceremonial uses). Critical water-related trust resources associated with instream flow needs and lake levels to support hunting, trapping, gathering, and other cultural practices are briefly described in Section 4.2.3.2, Environmental Resources. However, instream flow uses are incorporated in the Klamath River Basin Study through development of measures which are used to evaluate the impacts of climate change and implementation of adaptation strategies (refer to Chapters 5 and 6).

The federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. The tribes have reserved rights to water according to the Winters Doctrine of 1908. Additionally, the Interior Solicitor's Office stated that "Reclamation is obliged to ensure that project operations not interfere with the Tribes' senior water rights" (Interior, Office of the Solicitor, Pacific Southwest Region, 1995). And, absent a "completed adjudication or other determination of the senior water rights," projects must be "operated on the best available information" (Interior, Office of the Solicitor, Pacific Southwest and Northwest Regions, 1997). The same recognition is extended to other resources such as vegetation and wildlife.

With the exception of the Klamath Tribes, tribal water rights are not officially recognized (adjudicated) by California and Oregon. Oregon's Klamath Basin Adjudication process reached the end of its "administrative" phase in March 2013, and the OWRD reached its Final Order of Determination generally confirming the senior water rights of the Klamath Tribes. In general, tribes' water rights claims seek to assure adequate quantities of good quality water to maintain tribal trust resources including fish, instream flows, groundwater, minerals, and land as well as cultural values, which may be described as traditional religious practices, traditional food preparation, trade and barter of goods, and other practices that reinforce personal and tribal identity (North State Resources, Inc., 2012).

**Table 4-12. Klamath Basin Native American peoples**

| Klamath Basin Native American Cultures | Recognized Representative Tribal Government | General Location of Tribe in the Klamath Basin |
|---|---|---|
| Yurok | Yurok Tribe<br>Resighini Rancheria | Lower Klamath River<br>Lower Klamath River |

[23] Indian trust resources consist of certain real property, natural resources, and related rights, held in trust by the federal government for federally recognized Indian Tribes or individual Indians.

| | | |
|---|---|---|
| Hupa | Hoopa Valley Tribe | Lower Trinity River |
| Karuk | Karuk Tribe<br>Quartz Valley Indian Community | Middle Klamath River<br>Salmon River<br>Scott River |
| Shasta (Wairuhikwaiiruka/Kammatwa) | Quartz Valley Indian Community | Scott River<br>Shasta River<br>Upper Middle Klamath River |
| Modoc | Klamath Tribes | Upper Klamath Basin |
| Klamath | Klamath Tribes | Upper Klamath Basin |
| Snake (Yahooskin) | Klamath Tribes | Upper Klamath Basin |

*Source: North State Resources, 2012*

A portion of the adjudicated and non-adjudicated water rights of the tribes are for agricultural purposes. This consumptive use is addressed by Section 4.2.1.1, Agricultural Irrigation, which identifies the NIWR for existing crops within the basin. These demands are not differentiated between tribal and non-tribal uses.

Primary references for this and additional information related to tribal trust resources include the Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report (Interior and CDFG, 2012), the Trinity Mainstem Fishery Restoration Environmental Impact Statement/Environmental Impact Report (Interior et al., 2000) and the North State Resources, Inc. (2012) report, supporting the Secretarial Determination Overview Report.

#### *4.2.1.5 Livestock*

Livestock water use is included in the USGS Water Use Program estimates. However, because water use by livestock comprises only 0.2 percent of total estimated basin water use and is not likely to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

#### *4.2.1.6 Mining and Commercial/Industrial*

Mining and self-supplied commercial/industrial use is included in the USGS Water Use Program estimates. However, because this consumptive use comprises only 0.2 percent of total estimated basin water use and is not expected to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

### 4.2.2 Other Consumptive Uses and Losses

This section quantifies current losses associated with evaporation at the Klamath River Basin's primary lakes and reservoirs and evapotranspiration by emergent wetlands. Losses result in a reduction of water supply and are therefore included in the assessment of water supply and demand with the intent to quantify current water supply shortages.

#### *4.2.2.1 Wetlands*

This section briefly summarizes the estimation of current wetland ET used for the Klamath River Basin Study, using findings from Stannard et al. (2013). Additional work by Mayer and Thomasson (2004) was used for verification of estimated current wetland ET. Additional work by Bidlake (2002) over the more focused region of Tule Lake NWR was also reviewed in support of estimated wetland.

The Klamath River Basin Study estimates mean annual wetland ET over 341,154 acres of wetlands estimated by the National Wetland Inventory for emergent wetlands.[24] Wetland ET volume is based on work by Stannard et al. (2013), who found that during the average 190-day alfalfa-growing season wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. Estimates of average daily alfalfa and pasture ET were computed by the ET Demands model. For ET Demands model simulations, daily ET for multiple crops was computed for HUC8 sub-basins within the Klamath River Basin, similar to the approach taken by Reclamation (2014) in the West-Wide Climate Risk Assessment. Alfalfa and pasture ET computed by HUC8 sub-basin were used to estimate wetland ET. Use of the ET Demands model for these values, as opposed to alfalfa ET and pasture ET reported by Stannard et al. (2013), allows for direct comparison of the consumptive uses quantified by this study and also allows for evaluation of projected changes in wetland ET in a changing climate. Current mean annual wetland ET, based on estimates of alfalfa and pasture ET using the ET Demands modeling approach described above, is approximately 1,089,061 AFY (averaging wetland ET based on each of alfalfa ET and pasture ET). Estimates of current wetland ET by this study corroborates with the findings of both Stannard et al. (2013) and Mayer and Thomasson (2004), as shown in Table 4-13 in which current wetland ET in units of AFY were computed based on reported ET rates and the same estimated wetland area. This study's estimate of mean annual wetland ET is included in the overall estimate of current water demands provided in Table 4-4. It should be noted that the ET Demands model was not configured to include wetlands ET. However, future research involving the ET Demands model may involve determining model coefficients for wetland vegetation.

[24] http://www.fws.gov/wetlands/

**Table 4-13. Comparison of average annual current wetland ET from available sources**

| Source of Wetland ET Estimate | Average Annual Current Wetland ET (AFY) | ET Rate (ft/yr) |
|---|---|---|
| Mayer and Thomasson (2004) | 1,040,910 | 3.05 |
| Stannard et al. (2013) | 1,049,862 | 3.08 |
| Klamath River Basin Study | 1,089,061[25] | 3.31 |

Mayer and Thomasson (2004) measured and modeled estimates of fall water requirements for the seasonally flooded and permanently flooded wetlands at the Lower Klamath NWR, located in the Lost River HUC8 sub-basin. They found that 60 percent of the total volume of inflow to the wetlands goes to saturate the underlying soils, adding to the water needs of seasonally flooded wetlands. Once the soils are saturated, little loss to infiltration or groundwater seepage in the wetlands would occur. Annual water requirements for both types of wetlands were comparable. Wetlands with 50 percent emergent vegetation and 50 percent open water had an estimated annual ET of 3.05 feet per year over the period 1999–2001. Using the current estimated wetland area of 341,154 acres from the National Wetlands Inventory (USFWS, 2014) for emergent wetlands in the Klamath River Basin along with the above ET rate, the estimated mean annual wetlands ET would be 1,040,910 AFY.

Stannard et al. (2013) sought to improve understanding of ET losses from wetlands by taking ET measurements using the eddy-covariance method from May 2008 through September 2010 at two sites near Upper Klamath Lake. As noted above, they estimated the area of wetlands near Upper Klamath Lake as approximately 70 square kilometers (17,300 acres). From their ET measurements, they found that during the average 190-day alfalfa-growing season, wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. In this study, Stannard et al. estimated a wetland ET rate of approximately 3.08 feet per year. If we extrapolate their computed rate for wetland ET to include the area identified in the National Wetlands Inventory (341,154 acres), their resulting estimate of mean annual wetland ET is 1,049,862 AFY.

[25] Note that the mean ET rate was computed as the mean rate across HUC8 sub-basins, while average annual current wetland ET was calculated as the ET rate multiplied by area, each unique by HUC8 sub-basin, then summed over the entire basin. The average annual current wetland ET is not mathematically equivalent to the mean ET rate multiplied by the basin's 341,154 acres of emergent wetlands. Conversely, the average annual current wetland ET computed using methods by Mayer and Thomasson (2004) and Stannard et al. (2013) was computed as the ET rate multiplied by the total basin area.

#### *4.2.2.2 Lake and Reservoir Evaporation*

The reservoirs evaluated by the study are listed in Table 4-14 along with their capacity and ownership information. Historical evaporation rates (in inches per year) and volumes (in AFY) for these reservoirs have been estimated using an energy balance model, as described below. The historical rates provide the baseline against which future estimates are compared in later sections of this chapter.

**Table 4-14. Klamath River Basin primary reservoirs**

| Reservoir | Storage Capacity (AF) | Maximum Surface Area (acres) | Owner |
|---|---|---|---|
| Clair Engle Lake | 2,448,000 | 17,851 | Reclamation |
| Upper Klamath Lake | 629,780 | 90,000 | Reclamation |
| Clear Lake | 513,330 | 25,760 | Reclamation |
| Gerber Reservoir | 104,460 | 4,000 | Reclamation |
| Tule Lake | 60,592 | 13,074 | Reclamation |
| COPCO 1 Reservoir | 46,867 | 1,000 | PacifiCorp |
| Iron Gate Reservoir | 58,794 | 944 | PacifiCorp |
| John C. Boyle Reservoir | 3,495 | 420 | PacifiCorp |

*Source: PacifiCorp (2004c)*

The estimated evaporation rates for the Reclamation reservoirs in the basin were calculated using the complementary relationship lake evaporation (CRLE) model (Morton et al., 1985). CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimates of monthly evaporation. Reclamation collaborated with the DRI (Reno, Nevada) in the development and application of the model for this study.

The collaborative reservoir evaporation modeling effort with DRI was initiated as part of the WWCRA. Under the WWCRA work, Upper Klamath Lake evaporation was modeled along with 11 other reservoirs in the western U.S.

The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for Upper Klamath Lake. The model parameters for Upper Klamath Lake developed under the WWCRA were directly applied for simulation of open water evaporation in Upper Klamath Lake in this study. The other reservoirs listed in Table 4-14 were also modeled using the same approach.

The CRLE model calculates estimated evaporation for historical average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the analysis period (1950–1999). The same air temperature-based relationship used for estimating solar radiation for Upper Klamath Lake, based on Klamath Falls

Agrimet weather station data, was applied for modeling evaporation at the other reservoirs. Relationships for estimation of dewpoint depression (humidity) were developed based on historical data from the weather stations, discussed above in Section 4.2.1.1, Agricultural Irrigation, and as shown in Figure 4-2.

Table 4-15 includes a summary of the CRLE model results for the historical baseline period (1950–1999), including average annual evaporation rates and net evaporation (evaporation minus precipitation) rates for each reservoir. Table 4-15 also includes evaporation and net evaporation volume estimates based on the model results and historical average reservoir conditions. Note that historical average reservoir conditions differ from the maximum conditions reported in Table 4-14.

**Table 4-15. Klamath River Basin reservoirs evaporation model results summary for 1950 to 1999 historical baseline period**

| Reservoir | Evaporation (inches/year) | Evaporation (AFY)[26] | Net Evaporation (inches/year) | Net Evaporation (AFY)[11] |
|---|---|---|---|---|
| Clair Engle Lake | 45.0 | 49,152 | -26.0 | -28,412 |
| Upper Klamath Lake | 44.0 | 263,483 | 21.1 | 125,977 |
| Clear Lake | 45.6 | 81,711 | 32.0 | 57,300 |
| Gerber Reservoir | 44.4 | 8,947 | 24.1 | 4,862 |
| Tule Lake | 45.2 | 23,723 | 33.3 | 17,484 |
| COPCO 1 Reservoir | 43.9 | 3,427 | 20.8 | 1,626 |
| Iron Gate Reservoir | 44.8 | 3,446 | 27.2 | 2,089 |
| J.C. Boyle Reservoir | 44.2 | 729 | 22.5 | 371 |

Stannard et al. (2013) conducted an open water and wetland evaporation study for Upper Klamath Lake, Oregon. Bowen ratio energy balance was utilized to estimate open water evaporation during the summer and fall of 2008 and the growing seasons of 2009 and 2010. To evaluate the skill of CRLE application in the Klamath River Basin, the CRLE model was forced with measured solar radiation, air temperature, and dewpoint temperature obtained from the Klamath Falls Agrimet station for the 2008–2010 study period of Stannard et al. (2013). Results of the seasonal comparison are favorable, with daily average evaporation rates for this study of 0.20 inches per day compared to 0.21 inches per day by Stannard et al. (2013).

[26] Reservoir evaporation and net evaporation volumes were computed using mean monthly surface area over the simulation period.[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Deleted: ¶

#### *4.2.2.3 Operational Inefficiencies*
Operational inefficiencies such as canal seepage and on-farm losses associated with irrigation methods are not explicitly quantified in the Klamath River Basin Study. The largest irrigated region in the watershed is Reclamation's Klamath Project. Within the Project area, on-farm runoff and canal spills are captured in drains and reused such that the overall efficiency of the Project is considered to be relatively high. This is based on water budgets developed as part of previous studies (Davids, 1998; Freeman and Burt, undated; Reclamation, 2007b). For other irrigated regions, such as the Shasta and Scott Valleys, this study assumes that non-beneficial consumptive use of conveyance and on-farm losses is not a significant portion of the overall losses in the watershed. The USGS Water Use Program estimates for agricultural irrigation use include crop demands, conveyance losses, and on-farm losses.

#### *4.2.2.4 Phreatophyte Vegetation*
Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are included in the water budget through the natural flow computations (refer to Chapter 3) and therefore are not shown separately as losses. Needs of other vegetation for water are also included in the water budget. For example, BLM and USFS conservation initiatives associated with the 1994 Northwest Forest Plan preserve old growth vegetation and riparian buffers throughout the Southern Oregon / Northern California Coast Evolutionary Significant Unit and range of the Northern Spotted Owl (BLM and USFS, 2005).

### 4.2.3 Non-Consumptive Uses
Non-consumptive uses are those which do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.), water needs to support fish and wildlife, and hydropower production, among others. In one sense, these uses may be considered demands in that certain water levels or flows are required to support them. However, because these uses do not result in a loss of water in a planning context, the Klamath River Basin Study addresses them in terms of measures of system reliability. The measures are used to evaluate how well the available water supply is able to meet various needs in the watershed.

> **Non-Consumptive Uses**
>
> Non-consumptive uses include recreation, environmental resources, hydropower, and aquaculture. Because non-consumptive uses do not result in a reduction of available water supply, they are addressed in Chapter 5, System Reliability as measures for evaluating the impacts of climate change and implementation of adaptation strategies.

This section briefly describes the identified non-consumptive uses in the Klamath River Basin. However, details of water requirements and/or needs to sustain these uses are further quantified in Chapter 5, System Risk and Reliability Analysis.

#### *4.2.3.1 Recreation*

The expansive rural landscape of the Klamath River Basin offers a myriad of outdoor recreational opportunities, many of which are either directly or indirectly associated with the basin's water resources. Rivers, streams, and lakes are common throughout the basin's mountainous landscape, and reservoirs and wetlands exist in the valleys and high plateau areas of the central and eastern portions of the basin. The basin's rivers, streams, lakes, reservoirs, and wetlands provide a variety of recreational opportunities including camping, sightseeing, hunting, fishing, boating, hiking, and wildlife viewing.

There are five national forests within the basin (Klamath, Fremont, Winema, Six Rivers, and Modoc), a joint national and State park (Redwood), a national park (Crater Lake), two national monuments (Lava Beds and Cascade-Siskiyou) and five national wildlife refuges that make up the Klamath Basin NWR Complex (Klamath Marsh, Tule Lake, Clear Lake, Upper Klamath, and Lower Klamath). Recreation opportunities in these forests, parks, and refuges include camping, hiking, snowmobiling, sightseeing, wildlife viewing, hunting, and fishing.

Large sections of the Klamath River and its tributaries are designated as national wild and scenic rivers (WSR) under the Wild and Scenic Rivers Act, including segments of the Klamath, Scott, and Salmon Rivers and Wooley Creek totaling 297 miles. Extensive public and private recreational opportunities exist along the Klamath River and its tributaries.

The Klamath River Basin Study focuses on flow-related recreational uses, as they are more directly associated with water supply than other recreational demands such as camping and sightseeing, for example. The recreational uses considered in this study are fishing and boating in the Klamath and Trinity Rivers. Chapter 5, System Reliability quantifies optimal flow ranges for these activities, as reported by the Klamath Facilities Removal EIS/EIR (Interior and CDFG, 2012).

The modeling framework of the Klamath River Basin Study does not allow for evaluation of impacts of climate change on natural unmanaged lakes within the watershed; however, evaluation of reservoir levels is part of the system reliability analysis in Chapter 5.

#### *4.2.3.2 Environmental Resources*

Numerous fish species use the Klamath Basin during all or some portion of their lives. Native species include salmonids, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath River estuary. Salmonids in the Klamath River include fall and spring Chinook salmon; coho salmon; fall-, winter-, and summer-run steelhead; and coastal cutthroat trout. The salmonids share many similar life-history traits, but the timing of their upstream

migrations, habitat preferences, and distributions differ (Interior and CDFG, 2012). A number of non-native species have also been introduced into the watershed including yellow perch, largemouth bass, spotted bass, sunfish, and catfish. These species all have unique needs for Klamath River water which must be considered in conjunction with management practices for human uses.

**Water Quality**
Water quality in the Klamath River Basin is affected by both natural and human influences. The volcanic terrain supports soils that are naturally high in phosphorus. Human influences including development, wetland draining, agriculture, ranching, logging, and water management have altered streamflows and water temperatures and increased nutrient and sediment loading in the river system. In addition, mining activities, dam construction, and management for hydropower in the Lower Klamath Basin have further affected river conditions (Interior and CDFG, 2012). As a result of natural and human activities, water quality standards in the Upper Klamath Basin have not been met for many years (Stillwater Sciences, 2013). Table 4-16 summarizes the water quality impaired water bodies in the Klamath River Basin as identified by the Klamath Facilities Removal EIS/EIR (Table 3.2-8 in Interior and CDFG, 2012). The identified water quality impairments impact the beneficial uses of the Klamath River designated by the Klamath Facilities Removal EIS/EIR, which are categorized as Aesthetic and Cultural, Agricultural Water Supply, Commercial, Fish and Wildlife, Potable Water Supply, Industrial Water Supply, and Navigation.[27] For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.

[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

**Table 4-16. Water quality impaired water bodies within the area of analysis[1]**

| Water Body Name | Water Temperature | Sedimentation | pH | Organic Enrichment/Low Dissolved Oxygen | Nutrients | Ammonia | Chlorophyll-a | Microcystin |
|---|---|---|---|---|---|---|---|---|
| **Oregon[2]** | | | | | | | | |
| Sprague River and tributaries | $X^{S}$ | | $X^{S}$ | $X^{S}$ | | | | |
| Williamson River and tributaries | X | | | | | | | |
| Upper Klamath Lake and Agency Lake | | | X | X | | | X | |
| Upper Klamath River (Keno Dam to Link River Dam, including Keno Impoundment/Lake Ewauna) | | | $X^{S}$ | $X^{SP,S,F,W\ (3)}$ | | $X^{SP,S,F,W}$ | $X^{S}$ | |
| Upper Klamath River Oregon-California state line to Keno Dam (including J.C. Boyle Reservoir) (4) | $X^{SP,S,F,S\ (5)}$ | | | $X^{SP,S,F,W\ (3)}$ | | | | |
| **California** | | | | | | | | |
| Lower Lost River (Tule Lake, Lower Klamath Lake National Wildlife Refuge, and Mt. Dome) | | | X | | X | | | |
| Middle Klamath River Oregon-California state line to Iron Gate Dam (including COPCO Lake Reservoir [1 and 2] and Iron Gate Reservoir) | X | | | X | | | | X |
| Middle Klamath River Iron Gate Dam to Scott River Reach 6 | X | | | X | X | | | X |
| Shasta River | X | | | X | | | | |
| Scott River | X | X | | | | | | |
| Salmon River | X | | | | | | | |
| Middle and Lower Klamath River Scott River to Trinity River Reach 7 | X | | | X | X | | | X |
| Lower Klamath River-Trinity River to Mouth | X | X | | X | X | | | |

*Source: Table 3.2-8 in Interior and CDFG, 2012*

Notes:

1 While there are additional water quality impaired waterbodies in the area of analysis, the waterbodies listed in this table are the ones that are directly relevant to the water quality analysis for this Klamath Facilities Removal EIS/EIR.

2 Oregon lists specific reaches of the Klamath River by river mile and includes specific seasons, in some cases (Kirk et al., 2010).

3 Listed for dissolved oxygen only (non-spawning) (Kirk et al., 2010).

4 Oregon defines particular river miles for their listings.

5 Non-spawning (Kirk et al., 2010).

6 Selected minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include Beaver Creek, Cow Creek, Deer Creek, Hungry Creek, and West Fork Beaver Creek (USEPA, 2010a).

7 Minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include China Creek, Fort Goff Creek, Grider Creek, Portuguese Creek, Thompson Creek, and Walker Creek (USEPA, 2010a).

Key:

Sp = Listed for spring season
S = Listed for summer season
F = Listed for fall season
W = Listed for winter season

Effects on regional water quality have resulted in multiple federal, state, and tribal programs and planning documents to regulate and protect water quality in the area of the Klamath River Basin. For example, the states of Oregon and California have established and obtained EPA approval of water quality standards (referred to as “water quality objectives” in California) for waters in the Klamath River Basin, including designated beneficial uses (PacifiCorp, 2004b; Interior and CDFG, 2012). Also, several of the Klamath River Basin native tribes have adopted their own water quality objectives for portions of the Klamath and Trinity Rivers. Water quality objectives adopted by the Hoopa Valley Tribe establish water quality objectives for those portions of the Trinity and Klamath Rivers under the jurisdiction of the tribe. The Yurok and Karuk Tribes have also adopted water quality objectives, as has the Resighini Rancheria; however, the associated water quality plans have not yet been approved by USEPA (NCRWQCB, 2010b).

For water bodies included on the Clean Water Act Section 303(d) list of impaired water bodies, the state with jurisdiction over the water body must develop TMDLs to protect and restore beneficial uses of water. TMDLs set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. TMDLs have been established for various parts of the Klamath River Basin since about 2001. The status and pollutants regulated under Klamath River Basin TMDLs are summarized in Table 3.2-9 of the Klamath Facilities Removal Final EIS/EIR (Interior and CDFG, 2012).

Water levels and flow rates are inherently related to water quality in the Klamath River Basin. The need for improved water quality by environmental resources may be considered a demand, in one sense, because threshold flows are needed to sustain a healthy river system. However, because these needs are non-consumptive, the Klamath River Basin Study incorporates water quality criteria and associated TMDLs in the analysis of system reliability. Specifically, environmental health of the watershed is assessed through analysis of water temperature as a surrogate for overall watershed ecological health. Water quality criteria and TMDLs for stream temperature are incorporated as measures for evaluation of system reliability in Chapter 5.

**Instream Flow Targets**

Instream flow targets have been established for parts of the Klamath River Basin both through state codes, state and Federal regulatory requirements, and cooperative agreements such as Reclamation’s 2013 Biological Assessment for Proposed Klamath Project Operations and the associated 2013 non-jeopardy [28] Biological Opinion issued by the NMFS and USFWS. Instream flow targets are one means of working toward the maintenance and even recovery of threatened and endangered species in the basin. However, recommended instream flows are highly uncertain due to limited data availability and our limited understanding of

[28] An ESA Section 7 non-jeopardy Biological Opinion is one where USFWS or NMRS determines that a federal action is not likely to jeopardize the existence of a listed species or result in the destruction or adverse modification of critical habitat.

all of the direct and indirect effects of the environment on the species it supports. As we learn more about species recovery in responses to instream flow actions, these recommendations are likely to evolve through time.

Instream flow recommendations exist for reaches of the Klamath River (Reclamation, 2012d; NMFS and USFWS, 2013; Interior and CDFG, 2012; Hardy et al., 2006) as well as the tributaries of the Shasta River (McBain and Trush, 2014) and Trinity River (Interior, 2000). In addition, the federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. Interior supports Winters Doctrine rights which entitle tribes in the Klamath River Basin to sufficient water to support fishing and harvesting and cultural practices. Also, recognition of tribal reserved fishing rights is consistent with the federal precedent set in United States v. Adair (Interior and CDFG, 2012). Although the Klamath River Basin tribes have reserved rights to support their livelihoods, for the most part instream flow needs to support those activities have not been quantified, with the exception of the Klamath Tribes as part of Oregon's Klamath Basin adjudication process.

Similar to other non-consumptive water uses, recommended instream flow targets may be considered a demand in that certain flows are required to sustain fish species and support other uses. However, since these uses do not result in a reduction of water supply, they are incorporated in the analysis of system reliability in Chapter 5. Namely, instream flow targets may be used as measures in the evaluation of impacts of climate change on the watershed with and without implemented adaptation strategies. Details of recommended instream flow targets are included in Chapter 5.

**Wildlife Refuge Water Targets**

Klamath Basin National Wildlife Refuges is a complex of six refuges: Lower Klamath, Tule Lake, and Clear Lake in northern California and Bear Valley, Upper Klamath, and Klamath Forest Refuges in southern Oregon. All of the complex refuges are adjacent to or within Reclamation's Klamath Project with the exception of Bear Valley, which was established in 1978 and consists of old growth pine forest to protect a major night roost site for wintering bald eagles in Southern Oregon. The USFWS manages the refuges under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System (Reclamation, 2012d). They were established by various executive orders starting in 1908, and support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. Each year these refuges serve as an annual stopover for approximately three-quarters of the flyway waterfowl with peak concentrations of over one million birds. Reclamation manages leases on refuge lands for agricultural purposes through a cooperative agreement with the USFWS (Reclamation, 2012d).

The refuges (with the exception of Bear Valley and Clear Lake) have federally-reserved water right claims for the water necessary to satisfy the refuges' primary purposes subject to more senior water rights in the basin, including the Klamath Tribes and Reclamation's Klamath Project. The 2013 BA for Klamath Project operations outlines the availability of water to the Lower Klamath and Tule Lake NWRs (Reclamation, 2012d). In addition, Risley and Gannett (2006) estimated water needs of the Lower Klamath and Tule Lake NWRs using evapotranspiration estimates, with different rates for each of four land-use categories. With the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive. Recommended targets, like those summarized by the above sources, are provided in Chapter 5, System Reliability and incorporated as measures for evaluation of system reliability.

#### *4.2.3.3 Hydropower*

The Klamath River Basin has nine major hydropower generating facilities, seven in the Upper Klamath Basin and two in the Trinity River sub-basin. Other small hydropower generating facilities in the basin include the C Drop Plant on Reclamation's Klamath Project and two small hydropower facilities in Siskiyou County. The seven major hydropower plants in the Upper Klamath Basin are owned and operated by PacifiCorp of Portland, Oregon. The PacifiCorp facilities are regulated by the Federal Energy Regulatory Commission (FERC) as Project No. 2082 and are operating under annual licenses since the expiration of the original license in March 2006. Future operations are dependent on the resolution of the relicensing proceedings for these facilities, which may be addressed through either issuance of a new project license by FERC or the passage of federal legislation enacting the Klamath Hydroelectric Settlement Agreement (KHSA) and related Klamath settlements, which provide for the potential removal of these facilities.

Since 1992, operations of PacifiCorp's facilities have been adjusted to protect ESA-listed threatened species. These adjustments were made to address then-current minimum levels in Upper Klamath Lake and minimum instream flows in the Link River and in the Klamath River below Iron Gate dam described in biological opinions for Reclamation's Klamath Project (PacifiCorp, 2004b). The current river flow and Upper Klamath Lake level requirements are described in the 2013 Joint Biological Opinion for Klamath Project Operations by the USFWS and NMFS (NMFS and USFWS, 2013). If PacifiCorp's hydroelectric dams are removed as part of the KBRA/KHSA, the hydroelectric water rights at all of PacifiCorp's Klamath facilities (except Fall Creek) in Oregon will be dedicated or assigned to instream water rights and administered by the ODFW, while those in California will be abandoned, according to Section 7.6.5 of the KHSA.

The other two major hydropower generating facilities are located in the Trinity River sub-basin. The Lewiston powerplant provides power to the adjacent Trinity River Fish Hatchery and additional energy is sold. Trinity Power plant is a peaking plant associated with the Trinity River Diversion for Reclamation's Central Valley Project. Flow rates and associated power production at both

facilities are subject to the Trinity River Restoration Program Record of Decision (Interior, 2000).

The Klamath River Basin Study provides the basis for evaluations of changes in future hydrologic conditions and resulting changes in power generation capacity and timing. The analysis of system reliability (refer to Chapter 5) allows for quantification of projected turbine releases and hydropower production as a result of climate change and implemented adaptation strategies. This study does not evaluate projected changes in the demand for hydropower in a changing climate. Water rights and instream flow requirements associated with hydropower production are utilized in the system reliability analysis as measures for evaluation of changes in power production associated with various managed flow conditions in a changing climate.

#### *4.2.3.4 Aquaculture*

Another non-consumptive use of water within the Klamath River Basin includes aquaculture, which is defined as the rearing of aquatic animals. This use is quantified by the USGS Water Use Program; however, the percentage of total basin water use is only 3 percent. Due to the small percentage of overall water use, the fact that this use is largely non-consumptive, and the lack of information as to the impacts of climate change on aquaculture, this use is not further considered in the Klamath River Basin Study.

## 4.3 Effects of Climate Variability and Change on Demand

### 4.3.1 Climate Change Scenarios

The Klamath River Basin Study primarily utilizes climate change scenarios that are derived using an ensemble informed hybrid delta (HDe) method approach (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d). The scenarios are derived from both CMIP3 and CMIP5 bias corrected and spatially downscaled (BCSD) GCM climate projections, as these are considered equally likely potential climate futures at this time. The approach allows a high number of CMIP3 and CMIP5 climate projections to be distilled into a small number of representative climate change scenarios. The same scenarios used for evaluation of future water supply are used in this chapter's estimation of demands to meet consumptive uses, namely M&I and rural domestic as well as losses due to reservoir evaporation. Development of future agricultural scenarios involved using similar climate change scenarios, but with prior adjustments made to the underlying BCSD climate projections to account for biases in projected versus observed weather over irrigated areas (for more information, refer to WWCRA Demands Assessment, Reclamation, 2015).

Development of climate change scenarios is described in Section 3.5.1.2, Deriving Climate Change Scenarios from Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in

this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). Five scenario types are derived from the large number of CMIP3 and CMIP5 BCSD climate projections: warm-wet (WW), warm-dry (WD), central-tendency (CT), hot-wet (HW), and hot-dry (HD). Discussions of how the temperature and precipitation projections for the five HDe scenarios are used to estimate the various future demands are provided in the following sections.

### 4.3.2 Growth Scenarios

Future water demand with respect to consumptive uses and evaporation losses may have a number of driving forces aside from those directly related to climate, including demographics, land use, technological development, and socioeconomics. Because it is highly uncertain how these driving forces may unfold in the future, we employ a scenario-based approach to projected growth.

To evaluate the impacts of climate change on system performance of existing and anticipated water infrastructure and operations in the Klamath River Basin, a baseline condition is established. In typical long term planning studies, this baseline condition may be called the Future No Action alternative. A Future No Action alternative incorporates climate change scenarios and requires that assumptions be made regarding future growth in the watershed. The Future No Action alternative in the Klamath River Basin Study corresponds with one future growth scenario and ten climate change scenarios (five CMIP3-based scenarios and five CMIP5-based scenarios), each for the 2030s and 2070s, for a total of twenty future scenarios.

In general, the growth scenario encompasses projected population growth, where reported by the states and municipalities, and current agricultural practices. A brief description of the growth scenario is provided in this section. Assumptions regarding the future growth scenario are summarized below and in Table 4-17. Additional details regarding the growth scenario are provided in Section 4.3.3 which quantify the impacts of climate change on water demands.

As shown in Table 4-17, this study assumes that cropping patterns and number of irrigated acres are static in quantifying future agricultural irrigation demands. Altered cropping patterns may be considered in this study as implemented adaptation strategies in the analysis of system reliability. For M&I and rural domestic uses, a defined percentage of the water use is landscape irrigation and this is also considered static. Population estimates that define the total M&I and rural domestic future water usage are based on two primary sources. If population projections are provided by individual municipal water plans, those projections are incorporated into the demand scenario. For regions where municipal water plans may not exist, and for rural domestic water use, historical population trends are extrapolated into the future and incorporated in the demand scenario. For losses due to reservoir or lake evaporation, it is assumed that historical average reservoir levels exist in the future. Alternative future reservoir levels are considered as implemented adaptation strategies in the analysis of system reliability. Finally, for future wetland ET estimates, it is assumed that the current

number of wetland acres (based on the current National Wetland Inventory) is static.

**Table 4-17. Summary of assumptions for Klamath River Basin Study future growth scenario**

| Consumptive Use or Loss | Element | Assumptions for Future Scenarios |
|---|---|---|
| Agricultural irrigation | | |
| | Cropping patterns | Static, based on historical |
| | Irrigated acres | Static, based on historical |
| M&I and rural domestic | Landscape irrigation = 40 percent of total use | Static, based on historical |
| | Population growth | Based on water plans or extrapolations of historical trends (if projections not available) |
| Lake and reservoir evaporation | Average lake and reservoir levels | Static, based on historical |
| Wetlands ET | Wetland acres | Static, based on historical |

### 4.3.3 Projected Future Water Demands

Numerous factors were considered in the estimation of the basin's future water demands. The primary factors include population growth, agricultural practices, and climate change. Population growth, agricultural practices, and other socioeconomic conditions are incorporated in the demand scenario described above. Projections of climate change are incorporated separately, such that there are five HDe climate scenarios for each of the CMIP3- and CMIP5-based projections and for each future time horizon (2030s and 2070s). Each of these climate change scenarios is paired with the single demand scenario considered in this study.

As discussed previously, rigorous quantitative analyses were performed to estimate the demands to meet predominant consumptive uses in the watershed: agricultural irrigation, M&I, rural domestic, wetlands, and losses due to reservoir evaporation. The implications of climate change on non-consumptive uses are evaluated as part of Chapter 5, System Reliability Analysis.

Table 4-18 summarizes the projected changes in basin-wide consumptive use (both human influenced and natural) for the predominant use categories: agricultural irrigation, M&I, rural domestic, and losses due to reservoir evaporation and wetland ET. Projected changes are presented for all five HDe climate change scenarios for each of the CMIP3- and CMIP5-based projections, as well as for two future time horizons, the 2030s and 2070s.

**Table 4-18. Summary of basin-wide projected changes in consumptive water use and losses**

| Scenario | Period | BCSD Projection | Total (AFY) | Total Percent Change |
|---|---|---|---|---|
| Historical | Historical | - | 2,039,430 | - |
| Warm Dry | 2030 | CMIP-3 | 2,233,781 | 10% |
| Warm Dry | 2030 | CMIP-5 | 2,277,042 | 12% |
| Warm Wet | 2030 | CMIP-3 | 2,190,454 | 7% |
| Warm Wet | 2030 | CMIP-5 | 2,225,238 | 9% |
| Hot Dry | 2030 | CMIP-3 | 2,387,983 | 17% |
| Hot Dry | 2030 | CMIP-5 | 2,405,865 | 18% |
| Hot Wet | 2030 | CMIP-3 | 2,313,274 | 13% |
| Hot Wet | 2030 | CMIP-5 | 2,349,212 | 15% |
| Central Tendency | 2030 | CMIP-3 | 2,284,936 | 12% |
| Central Tendency | 2030 | CMIP-5 | 2,304,374 | 13% |
| Warm Dry | 2070 | CMIP-3 | 2,380,969 | 17% |
| Warm Dry | 2070 | CMIP-5 | 2,324,159 | 14% |
| Warm Wet | 2070 | CMIP-3 | 2,308,778 | 13% |
| Warm Wet | 2070 | CMIP-5 | 2,266,970 | 11% |
| Hot Dry | 2070 | CMIP-3 | 2,528,603 | 24% |
| Hot Dry | 2070 | CMIP-5 | 2,568,869 | 26% |
| Hot Wet | 2070 | CMIP-3 | 2,428,364 | 19% |
| Hot Wet | 2070 | CMIP-5 | 2,501,320 | 23% |
| Central Tendency | 2070 | CMIP-3 | 2,393,777 | 17% |
| Central Tendency | 2070 | CMIP-5 | 2,406,350 | 18% |

Similarly, for all future climate scenarios Figure 4-5 summarizes projected changes for each type of consumptive use or loss considered in the Klamath River Basin Study for the 2030s and 2070s.

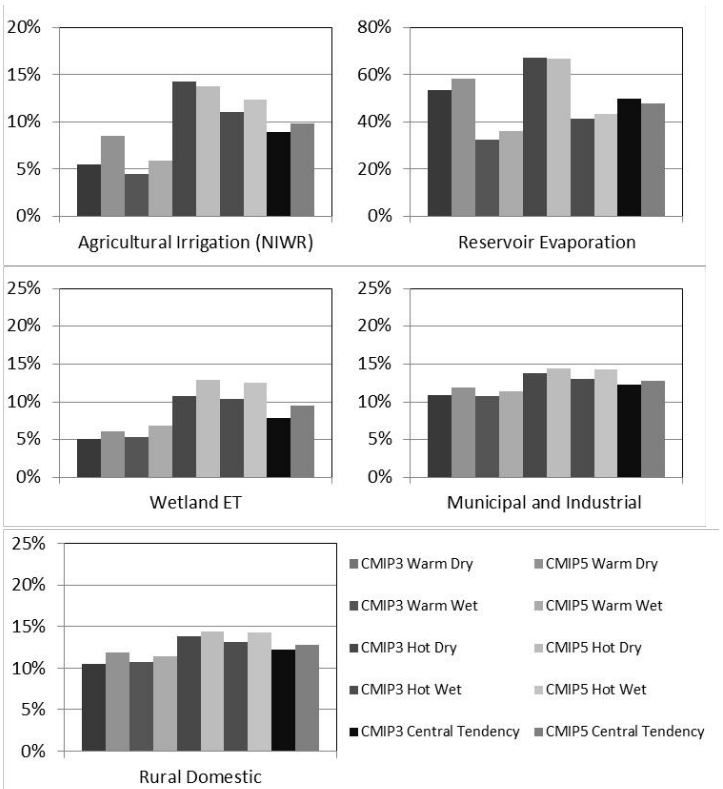


**Figure 4-5. Summary of basin-wide projected changes in consumptive water use and losses for the 2030s by use type**

#### *4.3.3.1 Human Influenced Consumptive Uses*

Projected consumptive uses to meet future demands are summarized in this section, incorporating projected HDe climate scenarios for two future time horizons, the 2030s and the 2070s, and a single future growth scenario. Descriptions of the approaches used to incorporate climate change scenarios and growth scenarios are provided in the respective subsections below on various consumptive uses and losses.

#### Agricultural Irrigation

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described in Section 4.2, Current Demand was implemented using the approach described in Reclamation (2015). Any differences in the approach details are discussed below.

For example, the Klamath River Basin Study utilizes two future time periods for analysis of climate change impacts (2030s and 2070s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA. Also, there are slight differences in the projection ensemble selection process for development of HDe scenarios. This study utilizes a subset of 10 climate projections to inform each of the five climate scenarios, while the WWCRA utilizes the full set of climate projections. Further discussion of the approach for climate change scenario development for this study is provided in Chapter 3. Another difference in approach for assessing agricultural irrigation demands is the use of both CMIP3 and CMIP5 projections in this study; the WWCRA uses solely CMIP3 projections. At the time the WWCRA work began, CMIP5 projections were not readily available.

As mentioned above, a single growth scenario was used in conjunction with multiple future climate scenarios to encompass a range of potential future consumptive water demands. Collectively these scenarios comprise the Future No Action scenario. This alternative generally includes historical cropping patterns and irrigated acreage. Additional approach details for assessment of future agricultural irrigation demands are provided in this section. In the discussion of Current Water Demands, the ET Demands model is described as using basal crop coefficient ($K_{cb}$) curves, which are developed as a function of GDD. For this study, the $K_{cb}$ curves for annual crops are developed using baseline (historical) temperatures, while perennial $K_{cb}$ curves are developed using future projected temperatures.

Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest, are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, static phenology $K_{cb}$ curves were simulated for future periods where historical baseline temperatures were used for simulating planting, crop development, and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal $K_{cb}$ curve shapes for each annual crop, and only exhibit differences in daily $ET_c$ magnitudes due to daily $ET_o$ and precipitation differences. A detailed discussion on this static phenology approach is included in Reclamation (2015).

The future irrigation demands results cover mean annual precipitation, temperature, reference evapotranspiration ($ET_o$), crop evapotranspiration ($ET_c$), and net irrigation water requirement (NIWR, both depth and volume). Mean monthly values of perennial crop $ET_c$ for future time periods and scenarios are also presented to highlight potential changes in seasonal $ET_c$.

The future $ET_o$, $ET_c$ and NIWR subbasin and basin total estimates were calculated using the same methods as the historical baseline values. Specifically, the NIWR and $ET_c$ rates for each crop within a given HUC8 subbasin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 subbasin,

and all crop values are summed to calculate weighted average HUC8 subbasin NIWR and $ET_c$ rates. $ET_o$, $ET_c$ and NIWR estimates for the entire basin were calculated using the ratios of subbasin to basin irrigated acres.

The results are summarized in a series of figures and tables (similar in format to the WWCRA [Reclamation, 2015]), with appended detailed results and additional figures. The figures below show projected changes in temperature, precipitation, $ET_o$, $ET_c$, and NIWR for the CMIP5-based climate scenarios and both future time periods (2030s and 2070s). CMIP3-based figures are shown in Appendix C. Projected changes are presented as the difference from historical baseline averages for temperature, and percent change from baseline averages for all other variables. Projected absolute values of $ET_o$, $ET_c$, and NIWR for the different scenarios and time periods are also included in Appendix C.

Figure 4-6 illustrates the spatial distribution of projected precipitation percent change for the different scenarios and time periods. Depending on the scenario, basin average precipitation percent changes range from -7.4 percent to +20.8 percent for the 2070 time period (considering CMIP5-based scenarios), with the central tendency scenario showing a general increase throughout the basin.

Figure 4-7 shows the spatial distribution of projected mean temperature change for the different climate scenarios and time periods. Increased temperatures are shown for all scenarios and periods. with slightly larger projected mean temperature changes in the northeast portion of the basin for all scenarios. Depending on the scenario, basin average temperature changes range from 1.6 to 8.4 degrees F for the 2070s time period (considering CMIP5-based scenarios).

Figure 4-8 shows the spatial distribution of projected $ET_o$ percent change for different climate scenarios and time periods, and Table 4-19 provides a comparison of projected changes in annual $ET_o$ for the central tendency climate scenario. Similar to temperature, the projected percent change in $ET_o$ is larger in the northeast portions of the basin.

Figure 4-9 illustrates the spatial distribution of projected $ET_c$ percent change for different climate scenarios and future periods, and Table 4-20 provides a comparison of projected changes in annual $ET_c$ for the central tendency climate scenario. Spatial differences in the distribution of projected percent change in $ET_c$ are largely due to differences in crop type and historical baseline $ET_c$. The northeast portion of the basin is projected to experience the largest percent change increase for all projected time periods, largely due to the fact that the difference between the projected and historical baseline $ET_c$ is fairly large relative to the baseline estimate of $ET_c$ (see Figure 4-4). The predominant crops in the Upper Klamath Basin include alfalfa, pasture grass, other hay, and winter wheat. In the Lower Klamath Basin, where alfalfa, other hay, and spring wheat are the dominant crops, projected increases in $ET_c$ are lower. The Lower Klamath HUC8 subbasin has a projected decrease in $ET_c$, despite projected climate warming in all

HUC8 subbasins. The increase may be due to projected changes in the harvesting of grass hay, which is projected to occur earlier in the year.

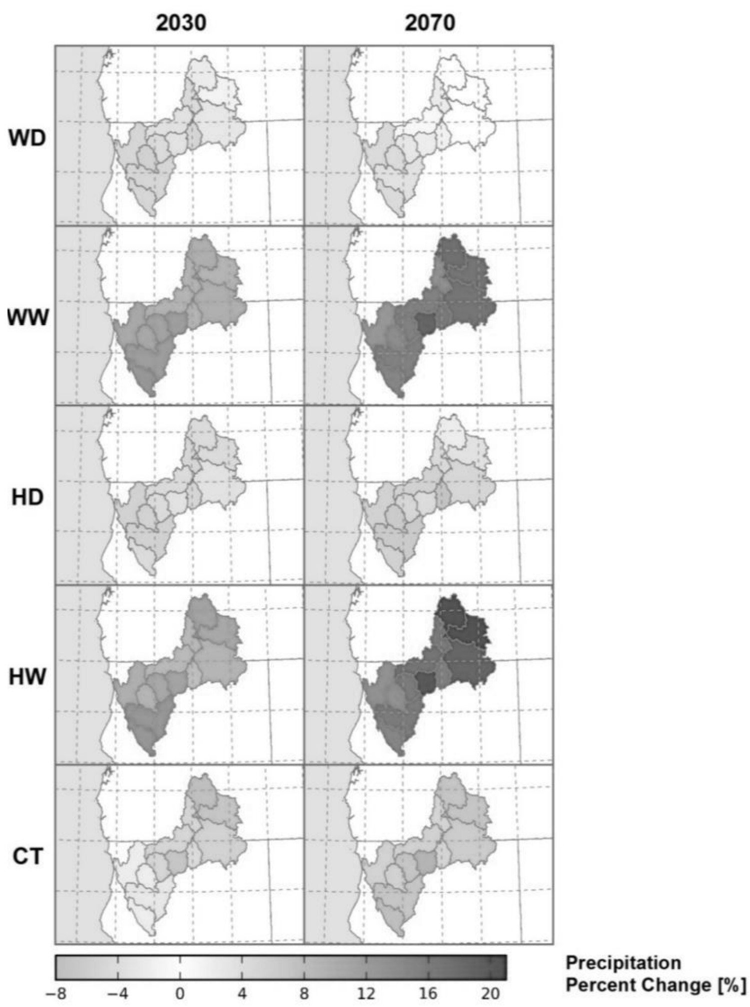


**Figure 4-6. Klamath River Basin - Spatial distribution of projected precipitation change for different climate scenarios and time periods (CMIP5 climate scenarios)**

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



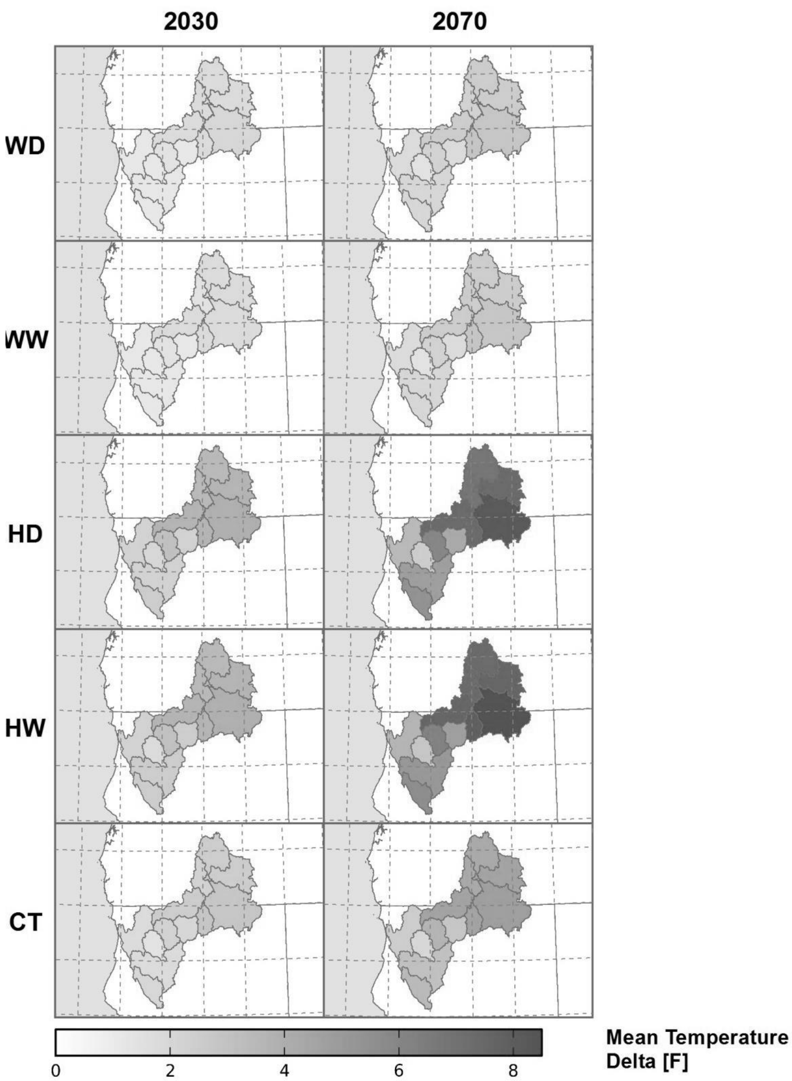


**Figure 4-7. Klamath River Basin - Spatial distribution of projected temperature change for different climate scenarios and time periods (CMIP5 climate scenarios)**

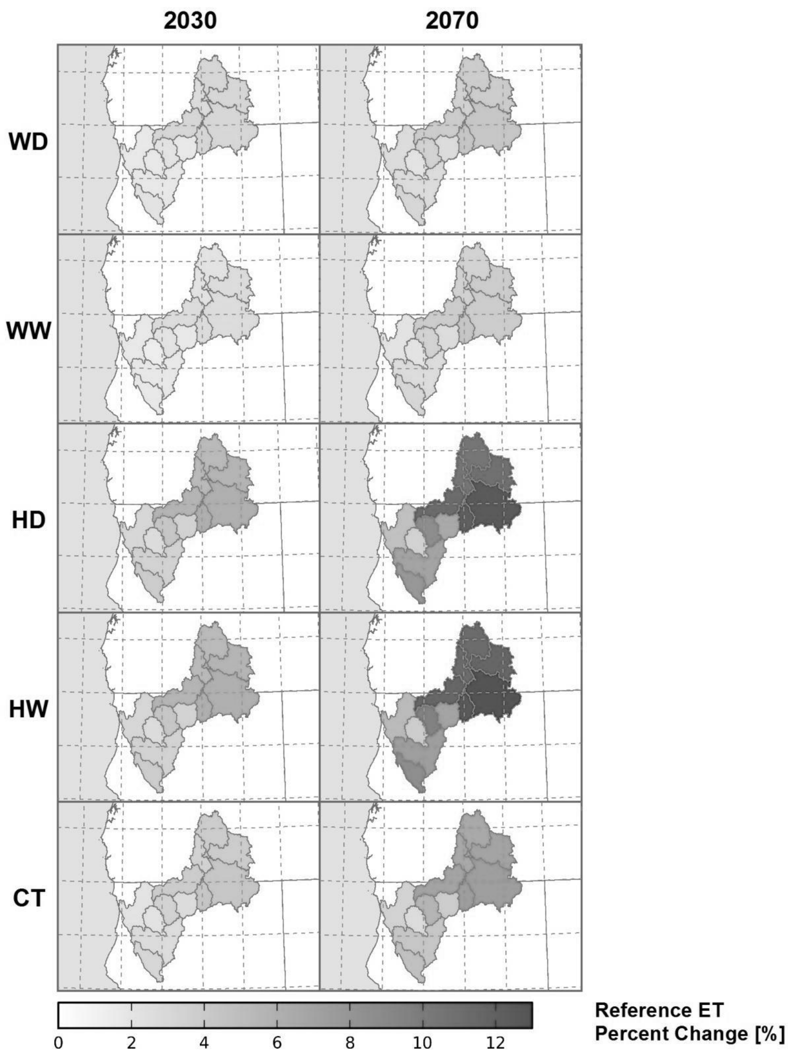


**Figure 4-8. Klamath River Basin - Spatial distribution of projected reference evapotranspiration percent change for different climate scenarios and time periods (CMIP5 climate scenarios)**

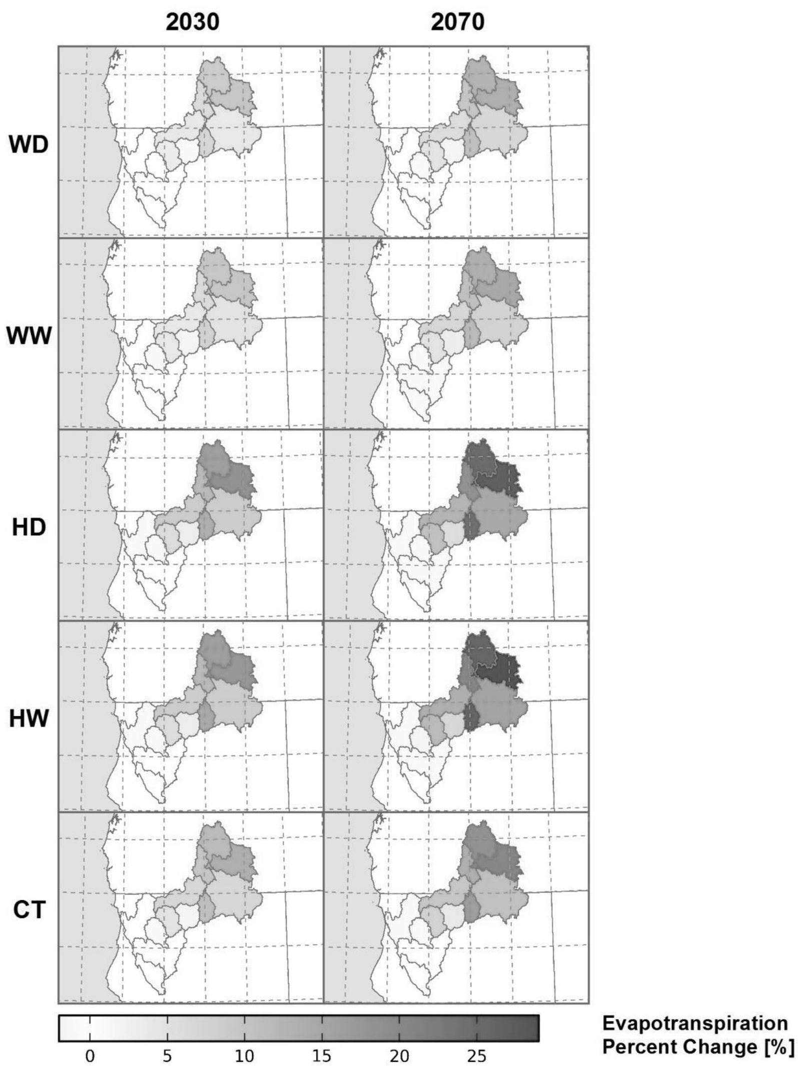


**Figure 4-9. Klamath River Basin - Spatial distribution of projected crop evapotranspiration percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).**

**Table 4-19. Comparison of projected changes in annual reference evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 3.3% | 3.8% | 5.9% | 6.43% |
| HUC_18010202 | Sprague | 3.4% | 4.0% | 6.1% | 6.7% |
| HUC_18010203 | Upper Klamath Lake | 3.2% | 3.7% | 5.7% | 6.3% |
| HUC_18010204 | Lost | 3.6% | 4.3% | 6.7% | 7.4% |
| HUC_18010205 | Butte | 3.7% | 4.4% | 6.6% | 7.4% |
| HUC_18010206 | Upper Klamath | 3.5% | 4.1% | 6.1% | 6.8% |
| HUC_18010207 | Shasta | 2.3% | 2.7% | 3.7% | 4.2% |
| HUC_18010208 | Scott | 2.8% | 3.4% | 4.9% | 5.5% |
| HUC_18010209 | Lower Klamath | 2.1% | 2.4% | 3.2% | 3.4% |
| HUC_18010210 | Salmon | 2.0% | 2.3% | 2.8% | 2.9% |
| HUC_18010211 | Trinity | 2.3% | 2.7% | 3.9% | 4.3% |
| HUC_18010212 | South Fork Trinity | 2.5% | 3.0% | 4.4% | 4.8% |
| Total Basin | | 3.4% | 3.9% | 6.0% | 6.7% |

**Table 4-20. Comparison of projected changes in annual crop evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins.**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 10.0% | 11.9% | 16.6% | 18.3% |
| HUC_18010202 | Sprague | 11.6% | 13.8% | 18.54% | 20.4% |
| HUC_18010203 | Upper Klamath Lake | 6.9% | 9.9% | 12.8% | 14.0% |
| HUC_18010204 | Lost | 5.7% | 6.8% | 9.6% | 10.7% |
| HUC_18010205 | Butte | 9.1% | 10.8% | 14.8% | 16.1% |
| HUC_18010206 | Upper Klamath | 5.4% | 6.6% | 8.9% | 9.7% |
| HUC_18010207 | Shasta | 2.2% | 2.6% | 3.9% | 4.4% |
| HUC_18010208 | Scott | 4.2% | 4.9% | 6.6% | 7.6% |
| HUC_18010209 | Lower Klamath | -0.7% | -0.9% | -1.1% | -1.2% |
| HUC_18010210 | Salmon | 1.0% | 1.1% | 1.3% | 1.4% |
| HUC_18010211 | Trinity | 0.7% | 0.8% | 0.8% | 0.9% |
| HUC_18010212 | South Fork Trinity | 0.8% | 0.9% | 0.7% | 0.6% |
| Total Basin | | 6.1% | 7.5% | 10.3% | 11.4% |

All HUC8 subbasins show positive $ET_c$ increases or no change, with the exception of the western-most HUC8 subbasin which exhibits slight decreases in $ET_c$ under all scenarios by 2070 due to earlier harvest of grass hay.

The spatial distribution of projected NIWR percent change for different climate scenarios and time periods is shown in Figure 4-10, and a comparison of projected changes in annual NIWR for the central tendency climate scenario is provided in

Table 4-21. The NIWR incorporates growing season and non-growing season soil moisture gains and losses from precipitation, bare soil evaporation, and ET; therefore spatial variations in the distribution of NIWR percent change for different time periods and scenarios are a function of respective $ET_c$ (Figure 4-9) and precipitation (Figure 4-6) distributions. For example, under the HD scenario precipitation is projected to decrease, whereas under the HW scenario precipitation is projected to increase. This results in NIWR increasing less in the HW scenario than in the HD scenario, though in both scenarios ETc changes are nearly identical.

**Table 4-21. Comparison of projected changes in annual NIWR for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 16.1% | 19.0% | 26.1% | 26.1% |
| HUC_18010202 | Sprague | 16.7% | 18.4% | 24.1% | 25.0% |
| HUC_18010203 | Upper Klamath Lake | 10.5% | 12.0% | 17.2% | 17.5% |
| HUC_18010204 | Lost | 8. 6% | 9.4% | 13.8% | 14.2% |
| HUC_18010205 | Butte | 12.7% | 13.9% | 20.5% | 20.4% |
| HUC_18010206 | Upper Klamath | 5.7% | 5.7% | 10.7% | 10.4% |
| HUC_18010207 | Shasta | 3.5% | 2.8% | 4.8% | 4.4% |
| HUC_18010208 | Scott | 5.5% | 6.5% | 8.7% | 9.1% |
| HUC_18010209 | Lower Klamath | -1.0% | -1.8% | -1.4% | -2.8% |
| HUC_18010210 | Salmon | 1.3% | 1.4% | 2.4% | 1.8% |
| HUC_18010211 | Trinity | 0.8% | 0.8% | 1.1% | 0.9% |
| HUC_18010212 | South Fork Trinity | 1.0% | 0.1% | 0.9% | -0.3% |
| Total Basin | | 9.0% | 9.8% | 14.1% | 14.4% |

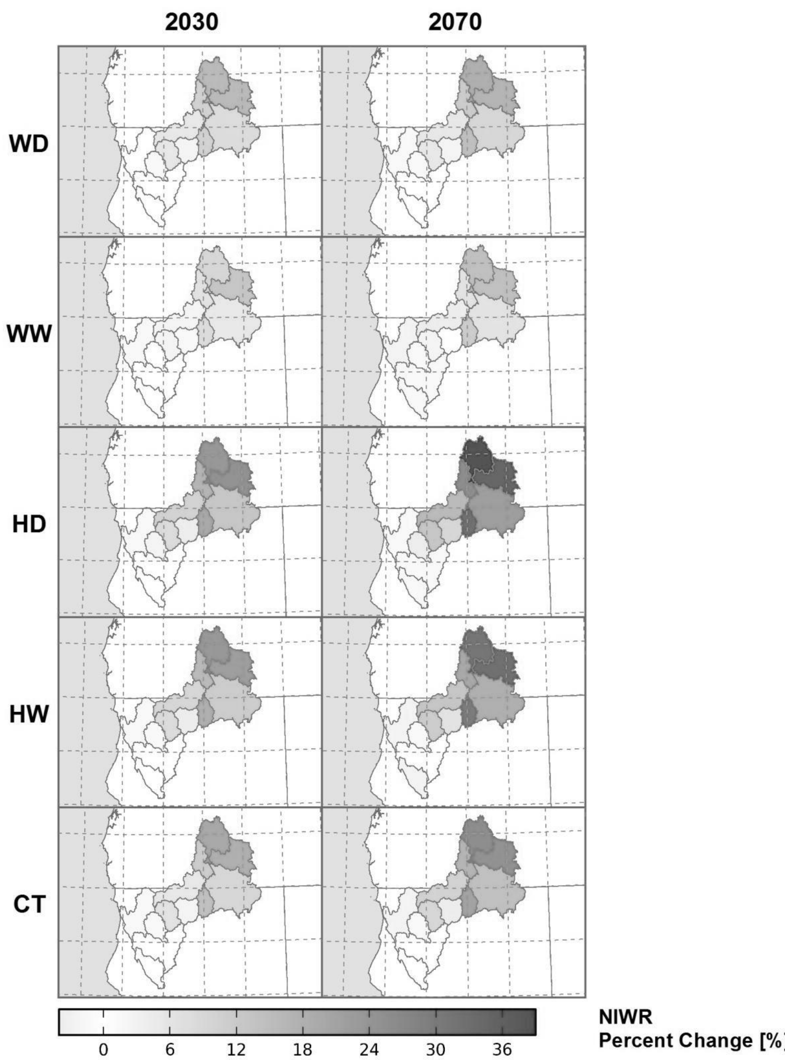


**Figure 4-10. Klamath River Basin - Spatial distribution of projected net irrigation water requirements percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios)**

Figures 4-11, 4-12, and 4-13 illustrate the historical baseline and projected temporal distribution of mean daily $ET_c$ for three perennial crops (alfalfa, pasture grass, and grass hay, respectively) under each CMIP5-based climate change scenario for the 2030s and 2070s. The values plotted in these figures are based on model results for Met Node OR4511 (NWS/COOP Klamath Falls Ag. Station).

## Future Irrigation Demand Results

Assuming no change from current cropping patterns, the projected change in the central tendency scenario for the 2070s over the basin is 6-7% for reference ET (corresponding primarily to projected changes in temperature), while the projected change in crop ET is 10-11% (which incorporates changes in timing of crop growth and harvesting), and the projected change in NIWR is about 14% (which reflects changes in soil moisture throughout the year).

Figure 4-11 shows slight but noticeable shifts in the growing season length and alfalfa cutting cycles relative to historical baseline conditions by the 2030s (left). By the 2070s time period (Figure 4-11, right) significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to baseline conditions, with the HW and HD scenarios exhibiting the most extreme changes. These simulations assume established crops rather than first year plantings. Projected changes in $ET_c$ are primarily realized through earlier green-up of alfalfa hay and changes in its cutting pattern. Senescence of the crop is delayed somewhat, but is primarily driven by day length. Maximum mean daily $ET_c$ during the warmest part of the year is not projected to increase substantially, primarily because plants have a maximum rate at which they can evapotranspire despite further increases in temperature.

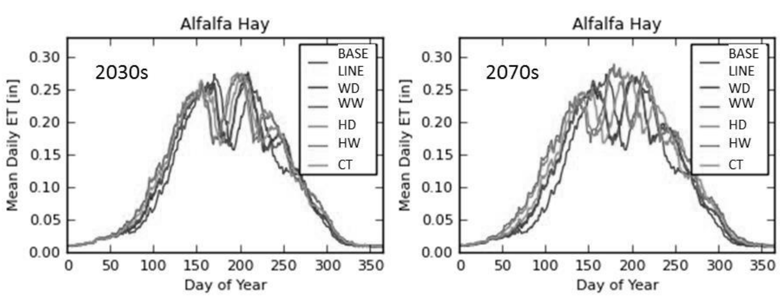


**Figure 4-11. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily alfalfa evapotranspiration for all CMIP5-based scenarios and time periods**

Figure 4-12 shows simulated mean daily $ET_c$ of pasture grass; similar changes in green-up and increases in growing season length and $ET_c$ are projected when compared to alfalfa, with the HW and HD scenarios having the most extreme seasonal changes.

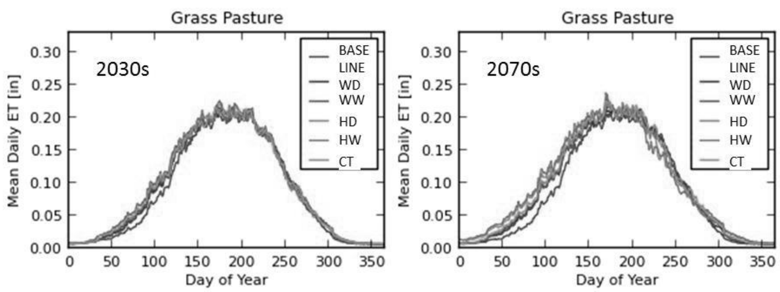


**Figure 4-12. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily pasture grass evapotranspiration for all CMIP5-based scenarios and time periods**

Figure 4-13 shows simulated mean daily $ET_c$ of grass hay. As with alfalfa and pasture grass, earlier green-up and increased mean daily $ET_c$ are slight for the 2030s and more pronounced for the 2070s. However, for the 2070s HW and HD scenarios, the overall growth period shifts forward rather than increasing in length. This is apparently due to the crop maturing earlier because of increased $ET_c$ early in the growing season under higher temperatures.

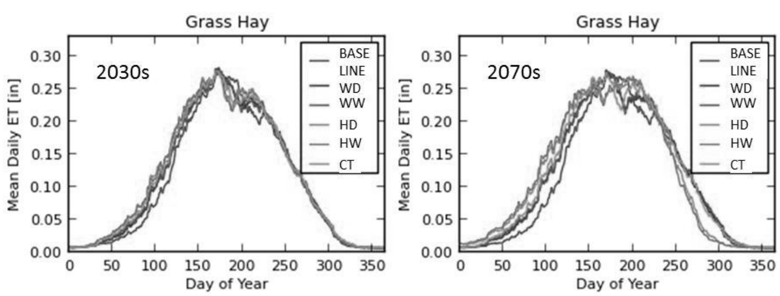


**Figure 4-13. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily grass hay evapotranspiration for all CMIP5-based scenarios and time periods**

**Municipal and Industrial**

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed current per capita demands will change as a function of changes in landscape irrigation demands due to climate change. Socio-economic factors that could cause changes in per capita demand, such as water conservation, reduced landscape areas, etc., are not accounted for in this chapter but are evaluated as potential adaptation strategies in Chapter 6. As previously discussed, 40 percent of total M&I use is assumed to be consumed through landscape irrigation.

The first step in estimating future M&I demands is to calculate the future base demands based on current demands and future population growth estimates (i.e., including growth scenario but no climate change scenarios). The base future demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the five climate change scenarios (WW, WD, CT, HW, and HD) using the two GCM projection datasets (CMIP3 and CMIP5). Forty percent of the base future demand estimate for a given period and scenario is increased based on the ET Demands model results.

The future M&I demand estimates for Klamath, Siskiyou, and Trinity Counties were calculated based on the 2005 USGS Water Use Program estimates and population growth rates published by the California Department of Finance[29] and Oregon Office of Economic Analysis.[30] Since the California and Oregon projections are for 2010 through 2060 and 2050 in five-year increments, respectively, it is assumed the growth rates from 2005 to 2015 are uniform as well for 2050–2070 (Oregon) and 2060–2070 (California). The product of the 2030 and 2070 county population growth rates and the 2005 county M&I estimates yields the base M&I demands for each county.

For the municipalities with domestic water supply systems in Del Norte, Humboldt, and Modoc Counties (Hoopa, Klamath, Newell, Orleans, and Willow Creek, all in California), county population growth rates published by the California Department of Finance were applied to the current (2010) population estimates for calculating future population estimates. The product of the 2030 and 2070 population projections and the current per capita demand estimates yields the base M&I demands for each of the systems in these municipalities.

As discussed above, each of the M&I base consumptive use estimates are adjusted for climate change. Figure 4-14 provides a summary of projected changes in M&I consumptive use for each county and each climate change scenario. The 2030 M&I consumptive use totals for all counties range from 9,759 AFY to

[29] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/
[30] http://www.dof.ca.gov/research/demographic/reports/projections/P-1/

10,065 AFY and the 2070 estimate totals range from 11,003 AFY to 11,747 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

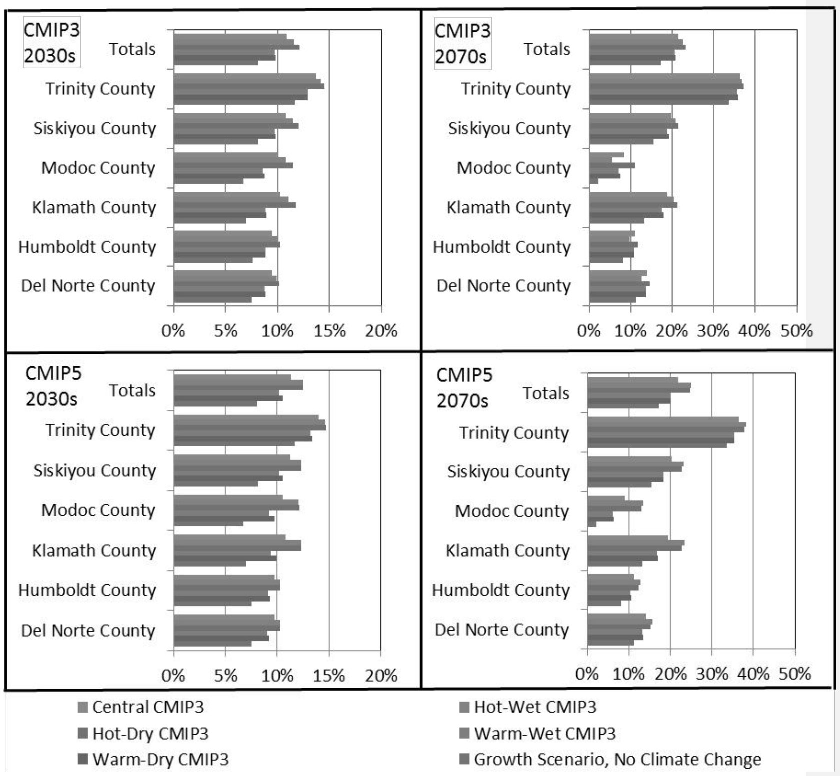


**Figure 4-14. Summary of future municipal and industrial consumptive use estimates (percent change)**

## Rural Domestic

Future rural domestic water demand estimates were calculated based on population growth projections and climate change scenarios in the same manner as the M&I estimates discussed above. The same portion of total use for landscape irrigation is assumed (40 percent). Therefore, projections of future rural domestic use include only the consumptive portion of total use.

As discussed under Section 4.2, Current Demand, it is assumed the demands associated with the limited number of rural domestic water users in the portions of the basin in Del Norte and Humboldt Counties in California and Lake and

Jackson Counties in Oregon are negligible. Estimates were therefore calculated for Modoc, Siskiyou, and Trinity Counties in California and Klamath County in Oregon. The population projections used in the calculations are based on the 2005 USGS Water Use Program information and county population projections published by the California Department of Finance and Oregon Office of Economic Analysis.

Figure 4-15 provides a summary of projected change in rural domestic consumptive use for each county and each climate change scenario. The 2030s estimate totals for all counties range from 5,013 AFY to 5,190 AFY and the 2070s estimate totals range from 5,644 AFY to 6,030 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

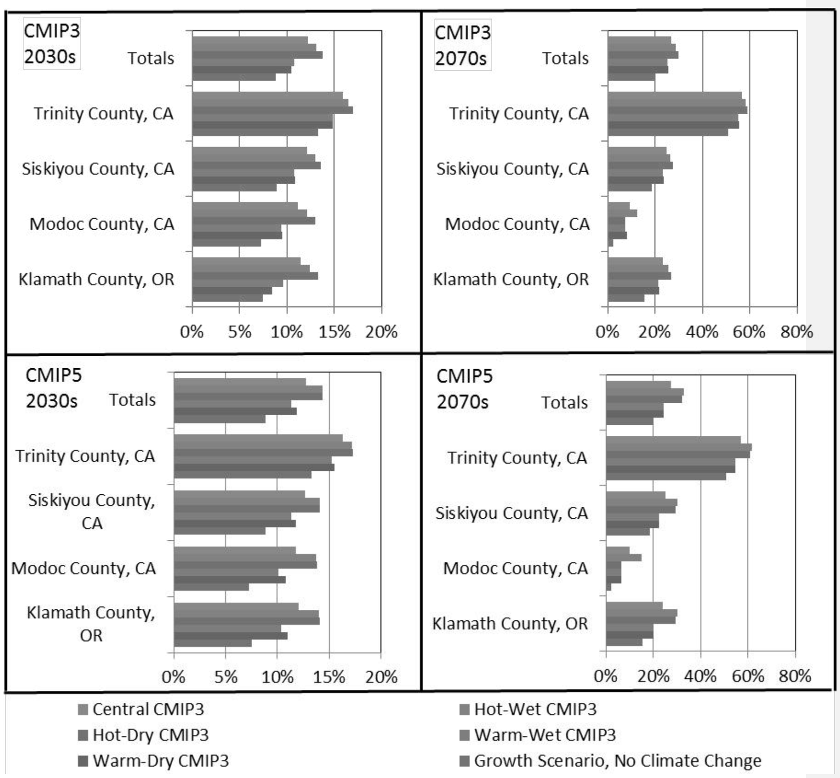


**Figure 4-15. Summary of future rural domestic consumptive water use estimates (percent change)**

#### *4.3.3.2 Wetlands*

Future wetland ET was computed based on projected mean daily alfalfa ET and pasture ET, using the same approach defined in Section 4.21, Human Influenced Consumptive Uses–Wetlands. Climate change scenarios using the HDe approach for each of the five quadrants of change for the 2030s and 2070s (using both CMIP3- and CMIP5-based projections) were also incorporated. The same relationships between wetland ET and alfalfa and pasture ET, according to the findings of Stannard et al. (2013), were used to determine projected mean annual wetland ET. Wetland ET is about 7 percent less than alfalfa ET during its average growing season and wetland ET is also about 18 percent greater than pasture ET during its average growing season. Mean annual wetland ET was computed using both relationships and averaged together for a single estimate.

Table 4-22 provides a summary of the resulting future wetland ET for each climate change scenario. The 2030s estimates range from 1,144,230 AFY to 1,228,916 AFY and the 2070s estimates range from 1,192,224 AFY to 1,319,673 AFY, compared with 1,089,061 AFY estimated for the mean annual historical wetland ET.

**Table 4-22. Summary of basin-wide projected changes in wetlands ET**

| Future Period and Scenario | Mean Annual Wetland ET (AFY) | Mean Annual Wetland ET (Percent Change) |
|---|---|---|
| Historical | 1,089,061 | - |
| 2030 Warm-Dry CMIP3 | 1,144,230 | 5% |
| 2030 Warm-Dry CMIP5 | 1,155,489 | 6% |
| 2030 Warm-Wet CMIP3 | 1,146,443 | 5% |
| 2030 Warm-Wet CMIP5 | 1,163,648 | 7% |
| 2030 Hot-Dry CMIP3 | 1,205,813 | 11% |
| 2030 Hot-Dry CMIP5 | 1,228,916 | 13% |
| 2030 Hot-Wet CMIP3 | 1,202,385 | 10% |
| 2030 Hot-Wet CMIP5 | 1,225,025 | 12% |
| 2030 Central CMIP3 | 1,175,143 | 8% |
| 2030 Central CMIP5 | 1,191,936 | 9% |
| 2070 Warm-Dry CMIP3 | 1,208,198 | 11% |
| 2070 Warm-Dry CMIP5 | 1,192,224 | 9% |
| 2070 Warm-Wet CMIP3 | 1,219,044 | 12% |
| 2070 Warm-Wet CMIP5 | 1,203,335 | 10% |
| 2070 Hot-Dry CMIP3 | 1,260,874 | 16% |
| 2070 Hot-Dry CMIP5 | 1,300,472 | 19% |
| 2070 Hot-Wet CMIP3 | 1,271,150 | 17% |
| 2070 Hot-Wet CMIP5 | 1,319,673 | 21% |
| 2070 Central CMIP3 | 1,237,064 | 14% |
| 2070 Central CMIP5 | 1,246,884 | 14% |

#### *4.3.3.3 Lake and Reservoir Evaporation*

The previously discussed CRLE model that was used to estimate historical baseline average evaporation rates was also used to estimate future average rates for the 2030s and 2070s periods. The same HDe climate change scenarios temperature and precipitation data described under the future agricultural irrigation demands discussion were input to the model. The model results include mean monthly evaporation and net evaporation (evaporation minus precipitation) rates for all of the reservoirs included in Table 4-14. The results for Upper Klamath Lake and Clair Engle Lake are discussed below, and the results for the other reservoirs are included in Appendix C, Section 5.0

Figures 4-16 and 4-17 show Upper Klamath Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and the historical baseline (1950–1999). The simulated impact of heat storage is negligible due to the shallow depth of Upper Klamath Lake. The magnitude of projected monthly evaporation and net evaporation increase is greatest during July, and least during fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Upper Klamath Lake is 5.5 and 5.4 percent (2.4 and 1.1 inches). Values for all scenarios are included in Appendix C, Section 5.0.

Figures 4-18 and 4-19 show Clair Engle Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and historical baseline (1950–1999). The simulated impact of heat storage due to the depth of Clair Engle Lake can be seen in the lag in peak evaporation relative to peak air temperatures (August versus July). Also, the relatively high precipitation rates result in negative net evaporation under all scenarios and the historical baseline. The magnitude of projected monthly evaporation and net evaporation increase is greatest during August, and least during the fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Clair Engle Lake is 5.7 and 9.0 percent (2.3 and -2.3 inches), respectively. Values for all scenarios are included in Appendix C, Section 5.0.

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



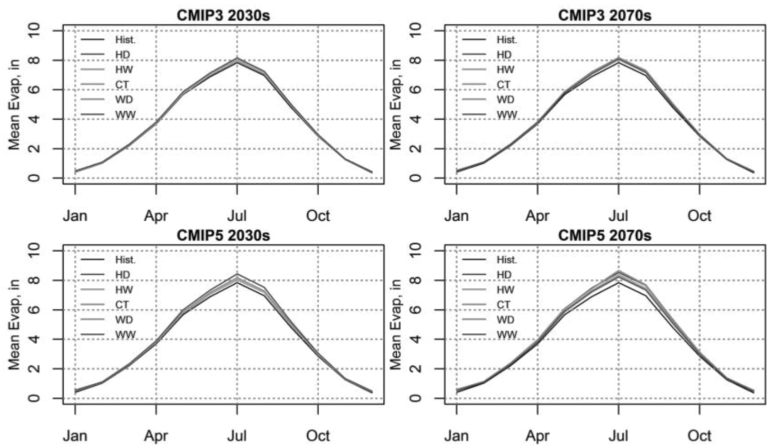


**Figure 4-16. Summary projected mean monthly evaporation at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

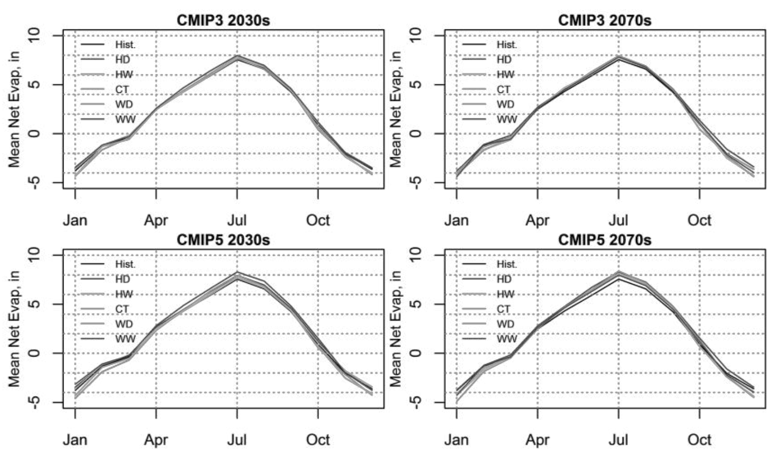


**Figure 4-17. Summary projected mean monthly net evaporation (evaporation – precipitation) at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

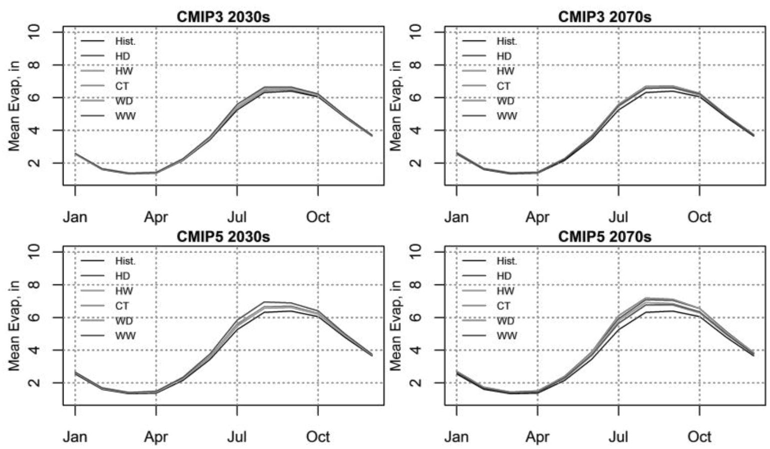


**Figure 4-18. Summary projected mean monthly evaporation at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

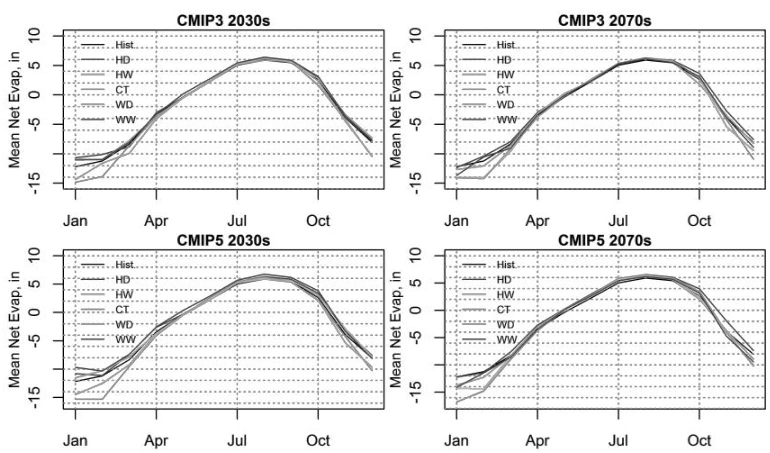


**Figure 4-19. Summary projected mean monthly net evaporation (evaporation – precipitation) at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

#### *4.3.3.4 Non-Consumptive Uses*

The effects of climate change on these uses (including recreation, environmental resources, hydropower, and aquaculture) are evaluated as part of the system reliability analysis in Chapter 5. In Chapter 5, the impacts are discussed in terms of factors such as exceedance of water quality criteria, flow or water level targets, and loss of power generation due to changing flows.

## 4.4 Uncertainties Associated with Impacts Assessment Approach

The Chapter 3 discussions on uncertainties associated with the various aspects of the Klamath River Basin Study water supply assessment covered many topics that also apply to the demands assessment. These topics include global climate forcing and simulation, climate projection bias correction and spatial downscaling, and climate projections from CMIP3 and CMIP5. Brief discussions of the limitations and uncertainties associated with quantification of water demands are presented below. A detailed discussion of uncertainties associated with the models used to estimate net irrigation water requirements (ET Demands) and reservoir evaporation (CRLE) are presented in Reclamation (2015) and are not detailed here.

### 4.4.1 Agricultural Irrigation

There are numerous uncertainties and limitations in modeling reference ET, crop ET, and net irrigation water requirements. One source of uncertainty is associated with underlying assumptions in modeling, such as static cropping patterns and farming practices. This study uses data provided by Reclamation's Klamath Basin Area Office for Klamath Project lands and the USDA crop land data layer for the remainder of the basin as the sources for quantifying the types of crops grown in the Klamath River Basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amount of irrigated area would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of net irrigation water requirements. Precipitation runoff and soil water holding capacity are a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 subbasin for which a weighted average soil type was calculated, as described in Reclamation (2015).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future

periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands, were not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using the assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

### 4.4.2 Municipal and Industrial and Rural Domestic

Uncertainties associated with M&I and rural domestic demands are related to the assumed population projections and per capita demand rates used, and the assumed landscape irrigation portion of the overall demand (40 percent).

### 4.4.3 Wetlands

Evapotranspiration from wetlands is difficult to quantify and a limited number of studies have been conducted in this area of research. Wetlands are biologically diverse and quantification of ET requires expensive long-term monitoring. Existing studies often based their findings on data collected over a limited time period, generally a few years, contributing to the uncertainty around their estimates. The Klamath River Basin Study utilizes available studies to estimate mean annual wetland ET. Although there is relatively high uncertainty surrounding the estimates of wetland ET in this study, they generally corroborate other existing studies and provide a best estimate of mean annual wetland ET.

### 4.4.4 Reservoir Evaporation

Uncertainties in estimated reservoir evaporation are largely centered on CRLE energy balance considerations, specifically heat storage and advection of heat in air and water into and out of the reservoir. One important limitation of the CRLE model is its reliance on energy balance without consideration of the effects of windspeed on evaporation. However, one could argue that using an approach that heavily relies on windspeed, and is therefore extremely sensitive to uncertainties in windspeed (i.e., the aerodynamic-mass transfer or combination approach), may actually increase evaporation uncertainty, especially under future climates where projections of near surface local scale windspeed estimates are extremely uncertain.

It is significant that reservoir evaporation and net evaporation (evaporation minus precipitation) demands were estimated in terms of annual rates or depths rather

than volumes. These rates were estimated based on average historical conditions and a more rigorous analysis would be required to model evaporation under predicted future reservoir conditions. Future research in the Klamath River Basin could involve adjusting the CRLE model to accommodate projections of future reservoir conditions.

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# Chapter 5
# Klamath River Basin Study
# System Reliability Analysis

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



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## 5.1 Introduction

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to work toward future water security. Reclamation developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (P.L. 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management. Studies are typically completed within a three-year timeframe. The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances.

This chapter discusses the methodology for evaluating gaps in water supply and demand and summarizes the reliability of the Klamath River system in achieving numerous defined measures, based on both historical data and projected future conditions.

Previous chapters of the Basin Study include an introduction and background for the study (Chapter 1), a discussion of various interrelated activities in the watershed (Chapter 2), an assessment of historical and future water supply in the watershed (Chapter 3), and an assessment of historical and future water demand in the watershed (Chapter 4). Chapter 6 discusses the development and evaluation of adaptation strategies for reducing gaps in water supply and demand within the system reliability framework discussed in this chapter. Figure 5-1 provides an overall schematic of the Basin Study approach to provide context for Chapter 5.

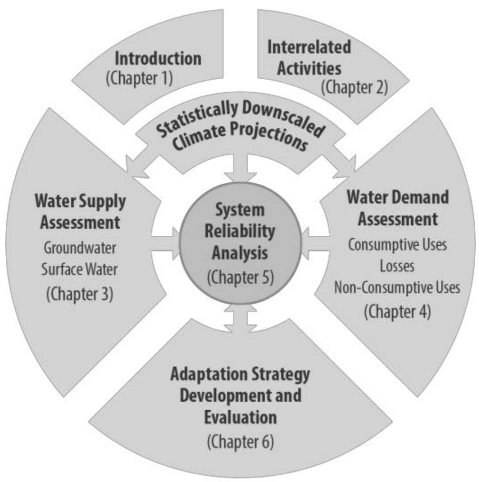


**Figure 5-1. Overall approach of Klamath River Basin Study, highlighting Chapter 5**

## 5.2 System Reliability Methodology

The Basin Study developed a framework for evaluating projected future water supply and demand conditions in a changing climate. This framework includes scenarios for characterizing projected future conditions, along with development and implementation of connected modeling components, with the end goal of evaluating system risk and reliability in the basin. Additionally, the Basin Study system risk and reliability analysis evaluates impacts of climate change on non-consumptive uses, which are those that do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.) and water needs to support fish and wildlife and hydropower production, among others.

This section briefly reviews the scenarios developed and corresponding modeling components implemented to provide inputs to a water management model. More detailed discussions of historical and projected water supply and demand are provided in Chapters 3 and 4, respectively. This section then provides a detailed description of the tools developed to evaluate system reliability and potential vulnerabilities to climate change impacts. Results from the analysis are evaluated using basin-wide response variables and defined measures to quantify and summarize projected changes in system reliability due to climate change.

### 5.2.1 Characterizing Historical and Future Conditions

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020–2049) and the 2070s (represented by the mean from 2060–2089). Future projections are compared with a historical reference period of 1950–1999 to evaluate the effects of climate change on water supply.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. The same dataset was used for analysis of historical conditions in the Basin Study. Historical trends in April 1 SWE, total annual runoff, total annual ET, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model (described in detail in Chapter 3).

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50 year period). All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999. Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide. Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent. ET, as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide. Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole. The only statistically significant trend at the 95th percentile level computed with the historical data is mean annual temperature.

The development of climate change scenarios is described in Chapter 3, Section 3.5.1.1 Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). The Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes available climate projections to derive a smaller number of climate change scenarios to inform long term planning. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios for each of two sets of projections (CMIP3 and CMIP5). These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT). These scenarios were derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d).

Projections of future water supply and demand using the above-discussed climate change scenarios and evaluated in Chapters 3 and 4, respectively, are briefly summarized below. Following this brief summary is a discussion of the methodology used to evaluate projected changes in managed streamflow and water temperature at various locations throughout the basin.

#### *5.2.1.1 Water Supply*

- By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

- Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

- A decrease in April 1 SWE is projected on the order of 34 to 40 percent for the 2030s and close to 60 percent for the 2070s, and projected increases in annual runoff are 7 to 12 percent for the 2030s and 14 to 15 percent for the 2070s. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE, primarily due to projected increases in mean annual precipitation,

- For sub-basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

- An increase in groundwater head is projected in mountainous recharge areas of the Upper Klamath Basin (less than 9 percent), as is a change in groundwater discharge to streams, while little change is expected in populated interior parts of the basin.

#### *5.2.1.2 Water Demands (Human Influenced)*

- Agricultural irrigation demand (surface and groundwater) is the largest human influenced consumptive use in the basin.

- Projected changes in total consumptive uses are 12 or 13 percent (CMIP3 and CMIP5 scenarios, respectively) for the 2030s and 17 or 18 percent for the 2070s. Consumptive uses include agricultural irrigation, net reservoir evaporation, municipal and industrial (M&I) and rural domestic demands, and wetlands.

- The effects of climate change on other non-consumptive uses including recreation, environmental resources, hydropower, and aquaculture are evaluated as part of this chapter.

### 5.2.2 Basin-Wide Responses

The evaluation of climate change impacts on system risk and reliability has two primary components: basin-wide system response at various basin locations, and specific performance measures that have been identified through discussions with regional resource managers, stakeholders, and others. Evaluation of basin-wide system response provides a general understanding of projected changes in managed conditions as a result of climate change and implemented adaptation strategies. Evaluation of system response to quantified measures provides a deeper understanding of climate change impacts on specific resources relevant to water management in the basin.

Basin-wide response variables include mean monthly conditions for the following locations:

- Mean monthly Upper Klamath Lake storage
- Mean monthly inflow to Klamath River at Keno
- Mean monthly streamflow, Klamath River at Iron Gate
- Mean monthly streamflow, Klamath River at Orleans, California
- Mean monthly streamflow, Klamath River near Klamath, California
- Mean monthly water temperature in the Klamath River near Klamath, California

This report includes analysis of historical and projected future changes in these basin-wide response variables, according to the developed Basin Study modeling framework. Subsequently, in Chapter 6, basin-wide response variables are evaluated for each of the adaptation strategies selected for exploring ways to reduce any identified water supply and demand gaps. Performance measures are described in more detail below.

### 5.2.3 Performance Measures

Performance measures are used to evaluate historical and future vulnerabilities to meeting water needs in the basin, and to facilitate the comparison of adaptation strategies to reduce any identified imbalances in water supply and demand.

Performance measures have been identified in accordance with the Basin Study Framework guidance document (Reclamation, 2009c) and span numerous resource categories, which include:

- Water deliveries – the ability for water to be delivered to water users
- Hydroelectric power resources
- Recreational resources – including Reclamation facilities and parts of the watershed impacted by Reclamation operations

- Ecological resources – including fish and wildlife habitat; applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973; species and habitat of cultural importance; and flow and water dependent ecological resiliency
- Water quality resources
- Flood control

Measures for each category were arrived at based on input from stakeholders and resource managers in the basin. Table 5-1 summarizes the performance measures. The following paragraphs describe each measure in more detail.

**Table 5-1. General description of performance measures**

| Resource Category | Measure Description | Location(s) | Measure Details |
|---|---|---|---|
| Water supplies | Total Klamath Project supply | Klamath Project | Calculated under 2013 Biological Opinion operating criteria. Compare result with full season Klamath Project supply of 390,000 acre-feet. |
| | Total Upper Klamath Lake seasonal supply | Upper Klamath Lake | End of February storage plus actual March through September inflow at Upper Klamath Lake |
| | Mean annual tributary flow | Shasta River; Scott River | Mean annual flow at USGS gages (USGS 11517500 Shasta River near Yreka; USGS 11519500 Scott River near Fort Jones) |
| Hydroelectric power resources | Hydropower production | Sum of J.C. Boyle power, COPCO 1 power, COPCO 2 power, Iron Gate power | Mean annual hydropower production summed over these facilities[31] |
| | Volume of spill | J.C. Boyle, COPCO 1, Iron Gate | Mean annual spill volume based on water year[1] |
| | Frequency of spill | J.C. Boyle, COPCO 1, Iron Gate | Mean number of spill days per water year at these facilities[1] |
| Recreational resources | Mean fishing days per year | Various mainstem Klamath River reaches | Mean number of days per year that flows are within acceptable ranges for select river reaches |

[31] Source: PacifiCorp

**Table 5-1. General description of performance measures**

| Resource Category | Measure Description | Location(s) | Measure Details |
|---|---|---|---|
| | Mean boating days per year | Various mainstem Klamath River reaches | Mean number of days per year that flows are within acceptable ranges for select river reaches |
| Ecological resources | Salmonid success | Shasta River; Scott River | Flow thresholds throughout the year[32] |
| | Delivery to refuge | Lower Klamath National Wildlife Refuge | Mean annual water delivery to refuge[33] |
| | Pool elevation | Clear Lake; Gerber Reservoir | Minimum elevation thresholds[34] |
| Water quality | Water temperature | Klamath River | Maximum weekly average temperature (MWAT) |
| Flood control | Frequency of flood control release | Upper Klamath Lake | Mean number of days per year that flood control releases are made from Upper Klamath Lake[35] |
| | Mean annual flood control release volume | Upper Klamath Lake | Mean annual volume of flood control releases from Upper Klamath Lake[5] |
| | Date of seasonal peak flow | J.C. Boyle, COPCO 1, Iron Gate | Mean date of the center of mass of the annual flow volume (by water year) at select locations[1] |

#### *5.2.3.1 Water Supplies – Klamath Project Water Supply*

There are two measures associated with Klamath Project water supply. The first measure is computed as the mean annual water supply to the Klamath Project, expressed as a percentage. The value may be compared with a full supply quantified as 390,000 acre-feet.

The second measure is computed as the sum of the end of February Upper Klamath Lake storage and the actual March through September Upper Klamath Lake inflow, averaged across the simulation years and expressed in units of a thousand acre-feet. The measure represents the total seasonal availability of water supply to be distributed among project responsibilities.

#### *5.2.3.2 Water Supplies – Mean Annual Tributary Flow in Shasta and Scott Rivers*

This measure is computed for two locations: USGS gages Shasta River near Yreka (11517500) and Scott River near Fort Jones (11519500). The measure is computed as the mean annual streamflow at these two locations. Effectively, the simulated streamflows represent the balance of supply and demand in these two

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[32] Source: McBain and Trush (2014)
[33] Source: Klamath Basin National Wildlife Refuge Complex
[34] Source: Klamath Basin Area Office
[35] Source: Reclamation (2012d)

tributary watersheds to the Klamath River. Units are in cubic feet per second (cfs).

#### *5.2.3.3 Hydroelectric Power Resources – Hydropower Production*
This measure is computed as the sum of mean annual hydropower production at J.C. Boyle reservoir, COPCO 1 reservoir, COPCO 2 reservoir, and Iron Gate reservoir. Units of hydropower production are megawatts.

#### *5.2.3.4 Hydroelectric Power Resources – Spill Volume*
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean spill per year in cfs.

#### *5.2.3.5 Hydroelectric Power Resources – Spill Frequency*
This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean number of days per year that each of the reservoirs have spill.

#### *5.2.3.6 Recreational Resources – Mean Annual Fishing Days*
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow (by the surface water management model) is within the target ranges for fishing in each river reach. Table 5-2 lists the recommended flow ranges for fishing.

**Table 5-2. Recommended target flow ranges for fishing within select reaches of the Klamath River**

| River Reach | Flow Target Ranges (cfs) |
|---|---|
| Keno Reach | 200-1,500 |
| J.C. Boyle | 200-1,000 |
| Hell's Corner Reach | 200-1,500 |
| COPCO 2 Bypass Reach | 50-600 |
| Iron Gate to Scott River | 800-4,000 |
| Scott River to Salmon River | 800-4,000 |
| Salmon River to Trinity River | 800-10,000 |
| Trinity River to ocean | 1,000-18,000 |

*Source: Interior and CDFG, 2012*

#### *5.2.3.7 Recreational Resources – Mean Annual Boating Days*
This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow by the surface water management model is within the target ranges for river boating in each river reach. Table 5-3 lists the recommended flow ranges for river boating.

**Table 5-3. Recommended target flow ranges for boating within select reaches of the Klamath River**

| River Reach | Flow Target Ranges (cfs) |
|---|---|
| Keno Reach | 1,000-4,000 |
| J.C. Boyle | 1,300-1,800 |
| Hell's Corner Reach | 1,000-3,500 |
| COPCO 2 Bypass Reach | 600-1,500 |
| Iron Gate to Scott River | 800-4,000 |
| Scott River to Salmon River | 800-7,000 |
| Salmon River to Trinity River | 800-10,000 |
| Trinity River to ocean | 1,000-18,000 |

*Source: Interior and CDFG, 2012*

#### *5.2.3.8 Ecological Resources – Salmonid Success in Shasta and Scott Rivers*

This measure is computed at two locations: USGS gages Scott River near Fort Jones (11519500) and Shasta River near Yreka (11517500). The measure compares simulated daily flow to quantified dry year flow targets recommended by McBain and Trush (2014) for the Shasta River. A dry year has an exceedance probability of between 61 and 100 percent. The measure is computed as the total number of days in a model simulation that dry year flow targets are met or exceeded, divided by the total number of days in the simulation and presented as a percentage. Dry year flow targets recommended by McBain and Trush (2014) are summarized below in Table 5-4. Note that the flow targets were developed for the Shasta River, where mean annual flow (188 cfs) is less than one third that of the Scott River (669 cfs). However, for purposes of this analysis the same threshold flows were applied for the Scott River to explore the frequency of meeting those same target flows in the Scott River.

**Table 5-4. Dry Year (61–100 percent exceedance) flow targets for salmonids**

| Time Period | Dry Year Target (cfs) |
|---|---|
| January 1 – March 31 | 135 |
| April 1 – May 15 | 170 |
| May 16 – June 15 | 150 |
| June 16 – September 15 | 70 |
| September 16  September 30 | 70-90 |
| October 1 – October 16 | 125 |
| October 17 – October 30 | 125-150 |
| October 31 – December 31 | 150 |

*Source: McBain and Trush 2014*

#### *5.2.3.9 Ecological Resources –Water Delivery to Lower Klamath National Wildlife Refuge*

This measure is computed as the mean annual water supply to Lower Klamath National Wildlife Refuge as simulated by the surface water management model. The measure is expressed in acre-feet.

#### *5.2.3.10 Ecological Resources – Pool Elevation at Clear Lake and Gerber Reservoirs*

This measure is computed at two locations: Clear Lake and Gerber Reservoirs. The measure compares simulated pool elevations at these locations with minimum pool elevations quantified for survival of Lost River and shortnose suckers. Minimum pool elevation for Clear Lake is 4,520.6 feet, while the minimum pool elevation for Gerber Reservoir is 4798.1 feet. The measure is computed as the mean percent of days that simulated pool elevations are at or above target pool elevations.

#### *5.2.3.11 Water Quality – Water Temperature*

This measure is computed as the maximum weekly average temperature (MWAT) in the mainstem Klamath River. The MWAT is the highest seven-day moving average of the daily mean river temperature. This measure is computed using the RBM10 stream temperature model developed by Perry et al. (2011). Details of the river temperature modeling approach and implementation are discussed in Section 5.3.2, System Reliability Model Development – Water Temperature Model. The MWAT is computed for each year and the mean of these temperatures across the simulation years is presented as the measure. Table 5-5 summarizes classifications of Poor to Very Good conditions for fish, along with associated temperature ranges, provided in the SONCC ESU coho salmon recovery plan (NMFS 2012).

**Table 5-5. Maximum weekly average temperature recommendations from the SONCC ESU salmon recovery plan**

| Maximum Weekly Average Temperature (MWAT) Classification | Temperature Range (degrees C) | Temperature Range (degrees F) |
|---|---|---|
| Poor | > 17.6 | > 63.68 |
| Fair | 16-17 | 60.8-62.6 |
| Good: | 15-16 | 59-60.8 |
| Very Good | < 15 | < 59 |

*Source: NMFS 2012, Appendix B*

#### *5.2.3.12 Flood Control – Flood Control Release Frequency*

This measure is computed as the mean annual percent of days where release from Upper Klamath Lake is specifically for flood control purposes. The unit of the measure is percent of days.

#### *5.2.3.13 Flood Control – Flood Control Release Volume*

This measure is computed as the mean annual volume of releases from Upper Klamath Lake specifically for flood control purposes. The unit of the measure is thousands of acre-feet (KAF).

#### *5.2.3.14 Flood Control – Date of Seasonal Peak Flow*

This measure is computed as the mean date of the center of mass of the annual flow volume (by water year) at select locations. The center of mass is defined as

the time at which half of the mean annual flow has passed the location of interest. The measure is presented as the mean date over the simulation period.

## 5.3 System Reliability Model Development

This analysis utilizes developed historical and future water supply and demand as input to a system risk and reliability model framework. The modeling framework involves two main components: the implementation of a surface water management model to generate simulated managed streamflow throughout the basin, and the implementation of a river temperature model to generate simulated water temperature in the mainstem Klamath River. The modeling components are described below in more detail.

### 5.3.1 Surface Water Management Model

A RiverWare surface water management model (Zagona et al., 2001) was developed for use by the Klamath River Basin Study. The RiverWare software platform allows for evaluation of river flows based on rule-based operations, using logic statements and assigned rule priorities. The RiverWare platform has been used in many other studies conducted by Reclamation and others (e.g., Colorado River Basin Water Supply and Demand Study [Reclamation, 2012e]; St. Mary River and Milk River Basins Study [Reclamation, 2012f]).

The Klamath Basin RiverWare model is a daily timestep model based on two existing models for the Upper Klamath Basin and Lower Klamath Basin. The existing Upper Klamath Basin model, commonly referred to as the Klamath Basin Planning Model (KBPM), was developed to support the ESA consultations over the impacts of Klamath Project operations on the endangered SONCC ESU coho salmon (Reclamation, 2012d). The existing Lower Klamath Basin model was developed to support the environmental impacts assessment for removal of four of the mainstem Klamath River dams (Interior, Department of Commerce, NMFS, 2012).

The Klamath Basin RiverWare model encompasses the entire watershed including tributaries of Upper Klamath Lake, the Lost River system, and major Klamath River tributaries such as the Shasta River, Scott River, Indian Creek, Salmon River, and Trinity River. The model includes representation of eight reservoirs: Upper Klamath Lake, Clear Lake, Gerber Reservoir, Lake Ewauna, J.C. Boyle Reservoir, COPCO 1 Reservoir, COPCO 2 Reservoir, and Iron Gate Reservoir.

The Klamath Basin RiverWare model was developed over a historical time period of water years 1961 through 2013 to facilitate comparison of results with the KBPM model. The historical model incorporates historical water demand information, and simulated water supply information from the water supply assessment in Chapter 3 in order for model validation to be performed. Once simulated flows were reached that sufficiently compared with results from the KBPM model, a separate historical model was developed using a period of record

of water years 1969 through 1999. The latter model incorporates simulated historical information from the water supply and water demands assessments in Chapters 3 and 4, respectively. This model was used as the basis for comparison of simulated streamflows under the historical climate to those under climate change scenarios.

The level of detail of the Klamath Basin RiverWare model allows for evaluation of Klamath River flows and Klamath Project operations under the current 2013 non-jeopardy Biological Opinion for SONCC ESU coho salmon, as well as evaluation of climate change impacts on other parts of the basin, including the Lost River and major Klamath River tributaries listed above.

Inputs to the Klamath Basin RiverWare model include the following:

- simulated natural surface hydrology from the VIC hydrologic model at various locations within the basin
- simulated groundwater discharge to streams in the Upper Klamath Basin as produced by the Gannett et al. (2007) MODFLOW model
- agricultural irrigation water requirements by 8-digit hydrologic unit code (HUC) throughout the Klamath Basin as produced by the water demands assessment (Chapter 4)
- net reservoir evaporation rates as produced by the water demands assessment (Chapter 4)
- M&I and rural domestic demands as produced by the water demands assessment

Outputs from the Klamath Basin RiverWare model include the following:

- Simulated managed flow at various locations in the Klamath Basin
- Reservoir storage and elevations
- Deliveries to the Klamath Project, Lower Klamath National Wildlife Refuge (LKNWR), etc.
- Hydropower generation

### 5.3.2 Water Temperature Model

The Klamath River Basin Study incorporates analysis of historical and projected future Klamath River temperature using an existing river temperature model developed by Perry et al. (2011). The river temperature model, called River Basin Model-10 (RBM10), was developed for the Secretarial Determination on removal of four hydroelectric dams on the Klamath River. It simulates water temperatures in the mainstem Klamath River from the Link River to the mouth. In this

application, water temperatures are computed at the Klamath River near Klamath, California.

RBM10 uses a simple equilibrium flow model, assuming discharge in each river segment on each day is transmitted downstream instantaneously. The model uses a heat budget formulation to quantify heat flux at the air-water interface. Inputs for the heat budget were calculated from daily-mean meteorological data including net shortwave solar radiation, net longwave atmospheric radiation, air temperature, wind speed, vapor pressure, and a psychrometric constant needed to calculate the Bowen ratio.

For the Klamath River Basin Study application, meteorological inputs used as part of the water supply assessment described in Chapter 3 were adjusted to match the statistics of the meteorological data used by Perry et al. (2011) in their study of the impacts of climate change and dam removal on Klamath River water temperatures. Input streamflows were taken directly from the Klamath Basin RiverWare model at locations consistent with the Perry et al. (2011) study. It should be noted that input streamflows were increased by 10 cfs in some Upper Klamath Basin reaches to prevent negative streamflows in the mainstem Klamath River. Negative Klamath River flows were possible due to the difference in handling of streamflow routing by the RBM10 and Klamath River Basin RiverWare models.

## 5.4 System Reliability and Impacts Assessment

Historical and projected future reliability of the Klamath River Basin water supply is summarized in two ways: through basin-wide response variables, and through identified reliability measures that were defined for six resource categories. This methodology was previously described in Section 5.2, System Reliability Methodology.

This chapter summarizes historical and projected changes in system reliability due to climate change alone. Chapter 6 discusses how various basin-wide responses and select measures may change as a result of implementing adaptation strategies.

### Impacts on Reservoir Storage

Mean end of month storage in Upper Klamath Lake generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, end of month reservoir storage did not historically fluctuate substantially through the year. Projections for the 2030s and 2070s indicate peak storage is likely to remain about the same or increase slightly.

### 5.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of historical and projected future basin-wide responses to water supply and demand allows for a general understanding of how the basin may respond as a result of climate change. Historical and projected future changes in water availability of the managed Klamath River system are provided below. Data supporting the following figures are provided in Appendix D.

#### *5.4.1.1 Upper Klamath Lake Storage*

Mean monthly end of month (EOM) storage in Upper Klamath Lake is summarized in Figure 5-2. Maximum storage historically occurs at the end of May, while minimum storage occurs in November. Under the climate change scenarios, mean EOM storage generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s, or even two months under the HW scenario. In addition, all scenarios experience a deeper drawdown of Upper Klamath Lake (UKL) than under simulated historical conditions and show minimum elevations in October compared to November (historical). Results in Figure 5-2 show that projected mean EOM storage is less under all future scenarios than under the simulated historical reference period. This result is likely due to use of the 2013 BiOp management criteria for all scenarios. Many management decisions rely on static look-up tables, which lack the flexibility to respond to different hydrologic conditions such as changes in Upper Klamath Lake inflow timing.

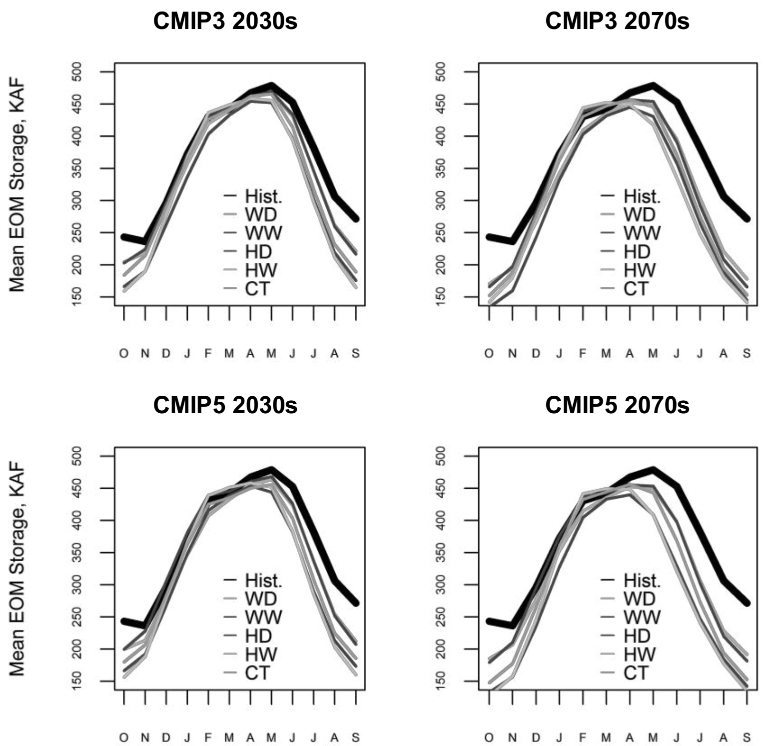



**Figure 5-2. Historical and projected future mean monthly Upper Klamath Lake storage (AF)**

### *5.4.1.2 Keno Dam Inflow*

Historical and projected future mean monthly inflow to Keno Dam is summarized in Figure 5-3. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. For the 2030s, the CT scenario indicates slightly higher peak flows while the HW and WW scenarios appear to have the highest increase in peak flow; the HD and WD scenarios show similar or slightly reduced peak flows. By the 2070s managed inflows to Keno Dam also appear to shift toward higher flows earlier in the year. Results indicate mean annual volumes increase under the wetter scenarios (HW and WW). Overall increases in Keno Dam

> **Mean Monthly Flow**
>
> Projections indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

inflow are primarily driven by increases in inflows to Upper Klamath Lake and thereby increases in Link River Dam outflows.

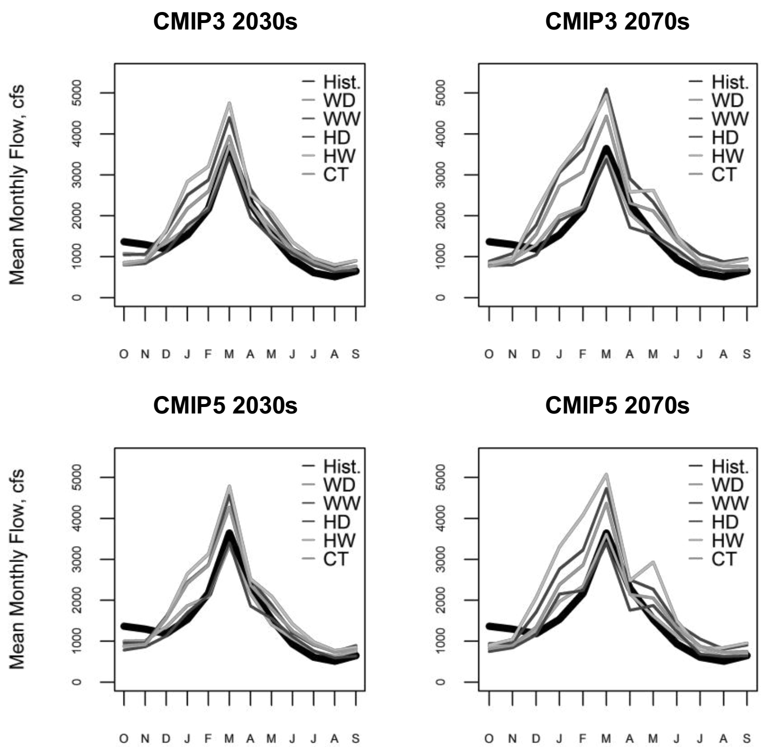



**Figure 5-3. Historical and projected future mean monthly managed inflows to Keno Dam (cfs)**

#### *5.4.1.3 Iron Gate Reservoir Storage*

Historical and projected future mean monthly Iron Gate Reservoir storage is summarized in Figure 5-4. Historically, EOM reservoir storage would peak in March and have its lowest storage in the summer months. Reservoir storage historically did not fluctuate substantially through the year, generally varying between about 55,000 acre-feet and almost 57,000 acre-feet. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase; none of the climate change scenarios indicate a reduction in peak reservoir storage.

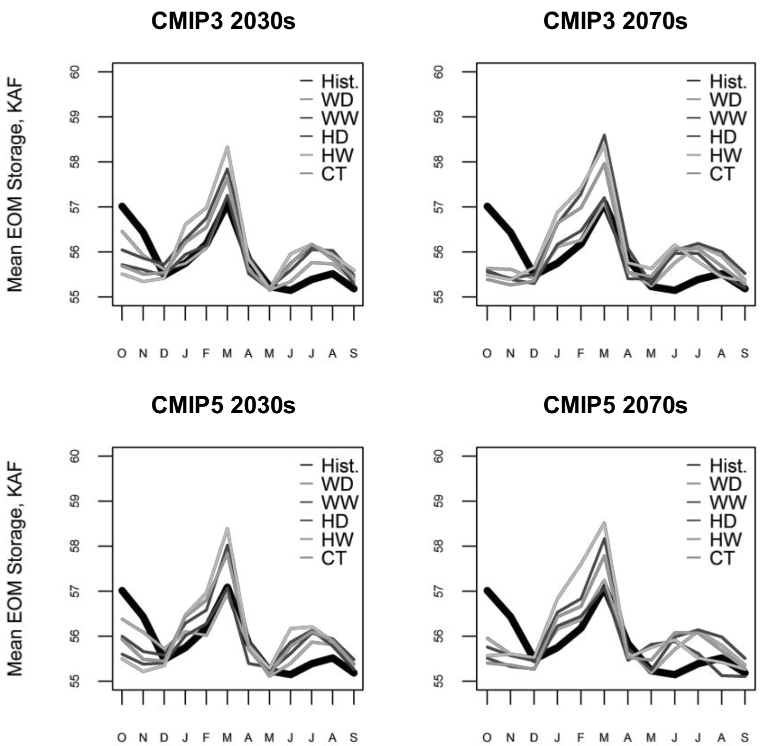



**Figure 5-4. Historical and projected future mean monthly Iron Gate Reservoir storage (KAF)**

#### *5.4.1.4 Iron Gate Reservoir Outflow*

Historical and projected future mean monthly outflow from Iron Gate Dam is summarized in Figure 5-5. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. Historical and projected changes in outflow at Iron Gate Dam correspond with those found at Keno, primarily due to their conjunctive management under the 2013 Proposed Action for Klamath Project operations. Projected changes in peak outflow are similar to Keno inflow in that the WW and the HW scenarios suggest the greatest increases. Also, particularly for the 2070s, substantial increases in flow during the months of January and February are projected. Differences between mean monthly inflows at Keno and outflow at Iron Gate from about May through September, namely projected increases at Keno and projected decreases at Iron Gate, are due to a combination of operating criteria and hydrology. Local inflows between Keno and Iron Gate are projected to decrease, which may contribute to the differences

during this period. Also during these months environmental flow requirements often govern operations, and these requirements are generally accounted for at Iron Gate Dam to maintain minimum flows. These operating criteria may result in differences in projected flows at the two locations.

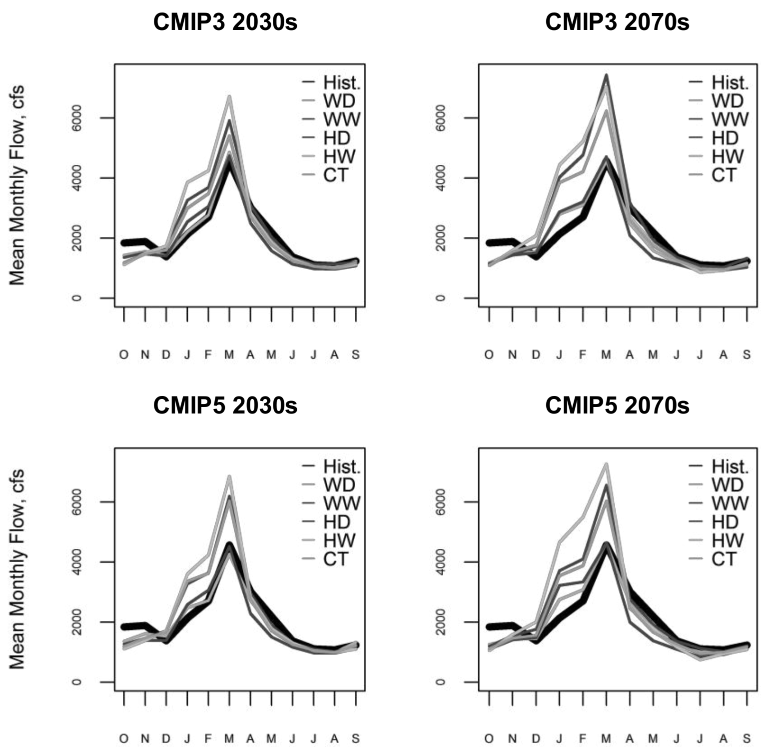



**Figure 5-5. Historical and projected future mean monthly Iron Gate Reservoir outflow (cfs)**

#### *5.4.1.5 Shasta River Flow*

Historical and projected future mean monthly flows in the Shasta River near Yreka are presented in Figure 5-6. Historical mean monthly flows exhibit a double peak, in January and again in March, the first corresponding with the period of seasonal peak rainfall and the second corresponding with snowmelt. The lowest flows occur during August. Projections of climate change indicate a range of increased snowmelt runoff contributing to streamflow (HW and WW scenarios) to decreased snowmelt runoff for the drier scenarios (HD and WD), with the central tendency similar or slightly less than historical. Flows during the

rainfall peak period are projected to increase for all but the WD scenario for the 2030s time period. By the 2070s, all scenarios project increased rainfall-driven peak flow in January. In addition, all but the WW scenario indicate reduced late spring flows, likely due to decreased snowpack (except for Mount Shasta, which is projected to experience increased snowpack due to increased precipitation and high elevations).

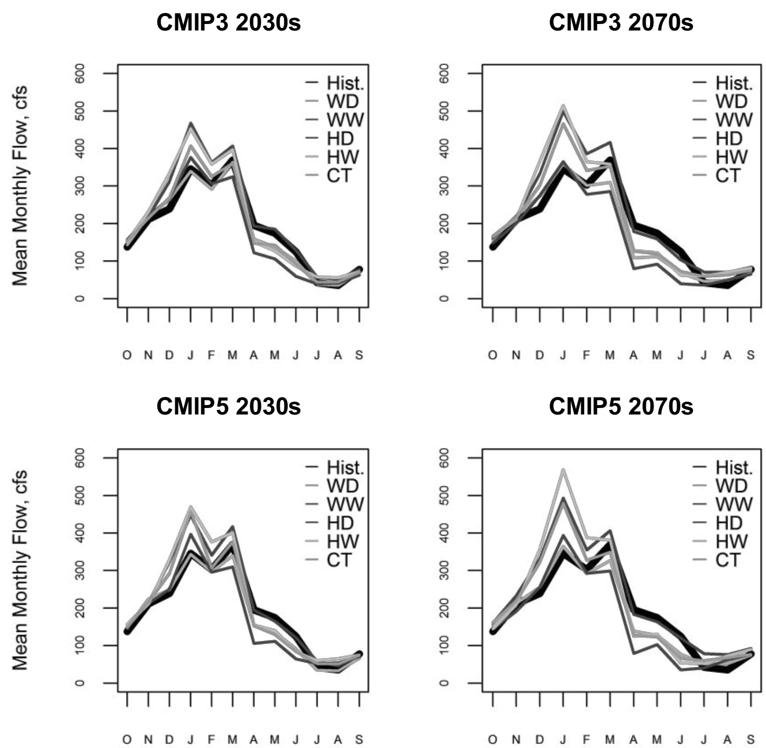



**Figure 5-6. Historical and projected future mean monthly flow in the Shasta River near Yreka (cfs)**

#### *5.4.1.6 Scott River Flow*

Historical and projected future mean monthly flows in the Scott River near Fort Jones are presented in Figure 5-7. The Scott River is a more rain-dominated watershed than the neighboring Shasta River watershed to the east. Historical mean monthly flows reflect a mixture of rain and snow during winter and early spring months, with seasonal peak flows occurring in March but closely followed by January and February. Climate change projections for both the 2030s and 2070s time periods, for both CMIP3 and CMIP5 based projections, indicate increased winter flows as a result of corresponding projected increases in precipitation. Also, the snowmelt runoff contribution to flow in the late spring months is projected to decrease.

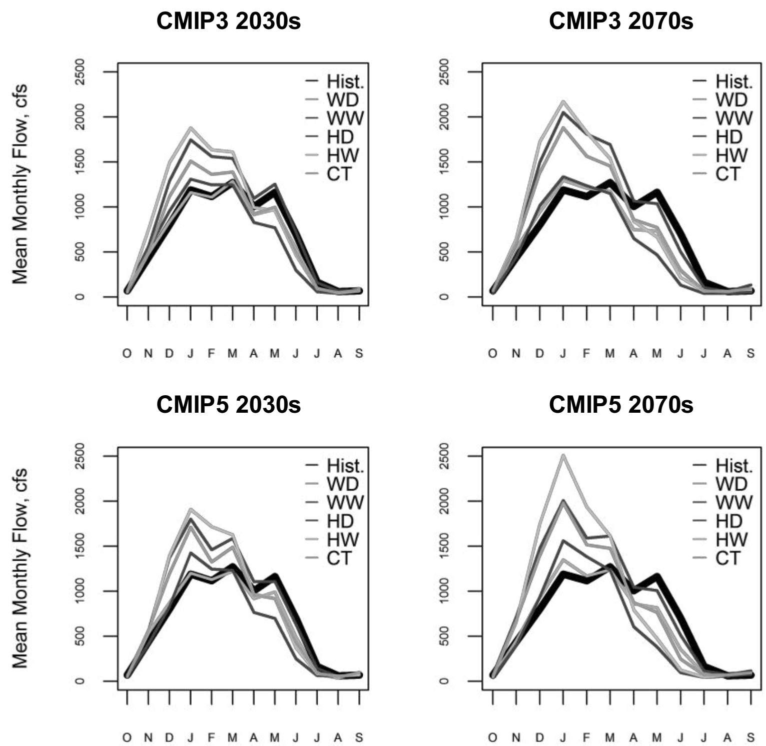



**Figure 5-7. Historical and projected future mean monthly flow in the Scott River near Fort Jones (cfs)**

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



#### *5.4.1.7 Flow at Klamath River near Orleans*

Historical and projected future mean monthly flows in the Klamath River near Orleans are presented in Figure 5-8. Managed flow in the Klamath River at Orleans reflects Upper Klamath Basin management and the contribution of tributary flows upstream of the Trinity River confluence. Historical mean monthly flows have a primary peak in March as a result of snowmelt runoff and a secondary peak in January as a result of winter rainfall. Projections of future conditions indicate increased peak flows for all scenarios, with the driest scenarios (HD and WD) similar in magnitude to historical. For the 2070s, a projected shift in the peak flow to earlier in the year corresponds with the reduced influence of snowmelt runoff as the climate warms and snowpack declines.

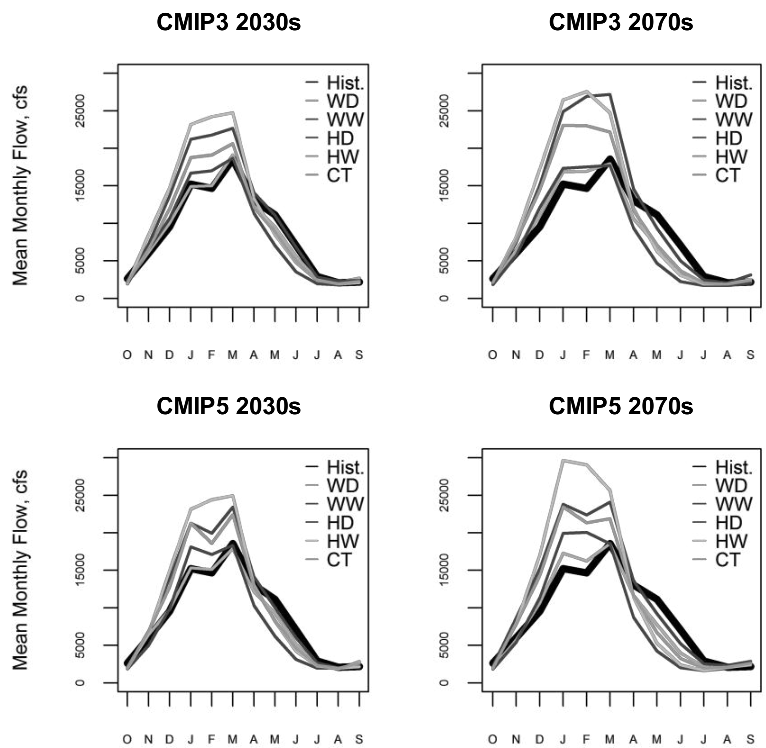



**Figure 5-8. Historical and projected future mean monthly flow in the Klamath River near Orleans (cfs)**

### *5.4.1.8 Flow at Klamath River near Klamath*

Historical and projected future mean monthly flows in the Klamath River near Klamath are presented in Figure 5-9. Simulated flows in the Klamath River at Klamath integrate managed flows in all of the Klamath River Basin, including contributions from the Trinity River which are affected by Central Valley Project exports to the Sacramento River Basin. Historical mean monthly flows at this location exhibit a double peak in January and March corresponding with rainfall and snowmelt runoff, respectively. Projected changes in mean monthly flows for all but the driest climate change scenarios for the 2030s indicate a shift toward a more rain dominated basin, with peak flows occurring January. Interestingly, projected mean monthly flows at Orleans (Figure 5-8) do not show the same shift, corresponding with a greater increase in January flows in the Trinity River, whose confluence with the mainstem Klamath River is located between Orleans and Klamath. This may be due to the methods used to develop Trinity River flows; Trinity and Lewiston reservoirs were not explicitly modeled and instead adjusted outflows were used as input to RiverWare based on relationships between simulated natural flows (developed in Chapter 3) and historical gage records.

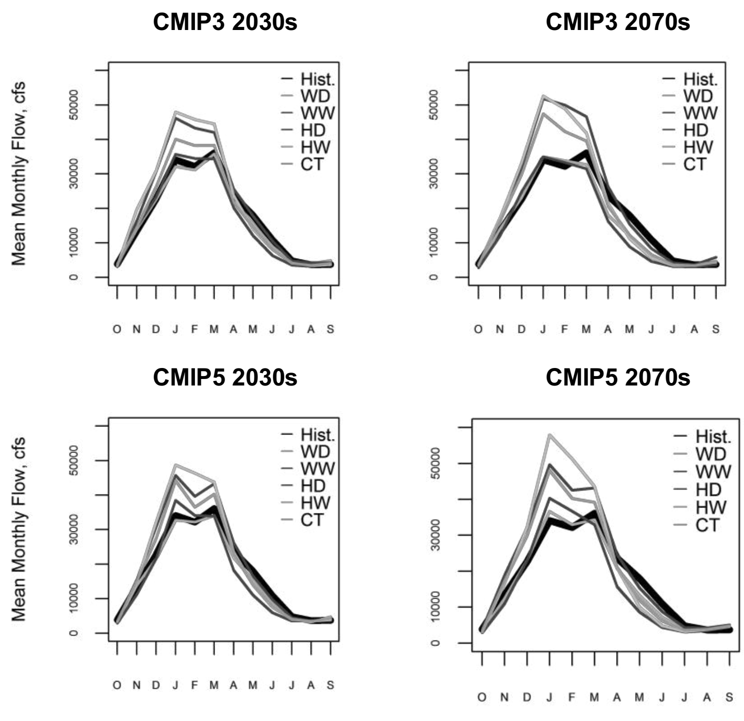



**Figure 5-9. Historical and projected future mean monthly flow in the Klamath River near Klamath (cfs)**

#### *5.4.1.9 Klamath River Water Temperature*

Historical and projected future mean monthly temperatures in the Klamath River near Klamath, as simulated by the RBM10 model, are presented in Figure 5-10. Historical water temperatures are at their maximum in August and at their minimum in January. Water temperature is projected to increase under all climate change scenarios considered by the study for both CMIP3- and CMIP5-based projections, and for both future time periods. Water temperatures historically are not favorable for salmon and projected increases in temperature exacerbate this issue.

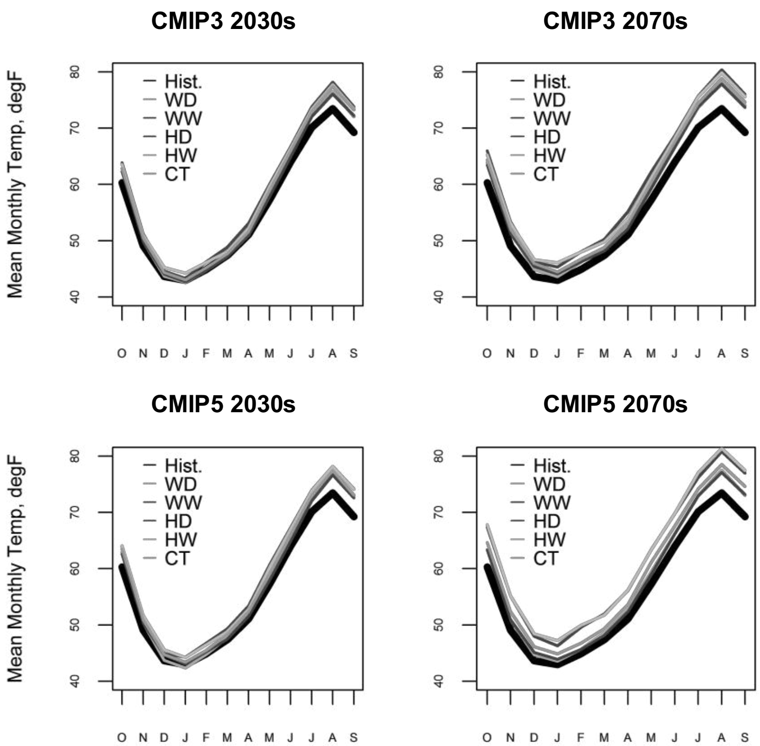



**Figure 5-10. Historical and projected future mean monthly water temperature in the Klamath River (degrees F)**

### 5.4.2 Analysis of Impacts – Ability to Deliver Water

To evaluate the ability of the Klamath River Basin to supply water to meet human needs, this study focuses on four measures: the percent of full irrigation water supply to the Klamath Project (from April through September), the mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow, mean annual flows in the Shasta River near Yreka, and mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

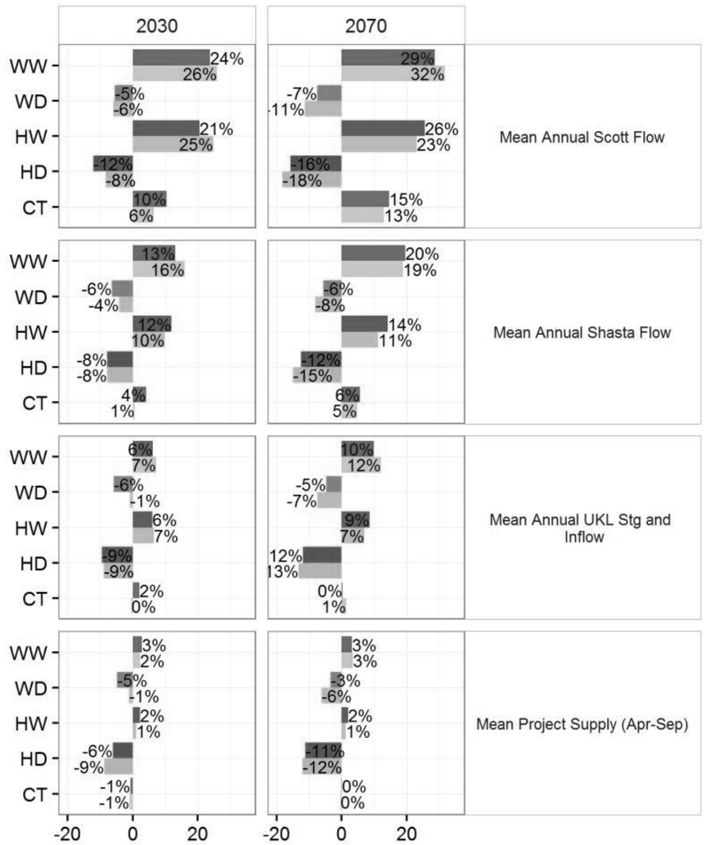
Water supply measures under simulated historical conditions are provided in Table 5-6, while projected changes in these measures are illustrated in Figure 5-11. Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the simulation period, the sum of end-of February storage plus March–September inflows at Upper Klamath Lake (another indicator of total available supply from Upper Klamath Lake) was about 1.38 million acre-feet. Additional measures representing the total water supplies in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

**Projected Klamath Project Supply**

Klamath Project irrigation deliveries average about 93 percent of full supply under historical hydrology according to simulations by the Klamath Basin RiverWare Model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

**Table 5-6. Historical measures related to water supply.**

| Measure | Historical Value | Units |
|---|---|---|
| Mean Klamath Project supply | 361.3 | KAF |
| Mean annual UKL seasonal supply | 1,378 | KAF |
| Mean annual Shasta flow | 187.7 | cfs |
| Mean annual Scott flow | 668.8 | cfs |




Notes: Changes are represented as percentages; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-11. Projected changes in water supply measures**

In terms of the projected changes in water supply measures shown in Figure 5-11, projected changes in mean annual flow in the Scott and Shasta Rivers include increases for the wetter scenarios (WW and HW) close to about 20 percent for the 2030s and 30 percent for the 2070s and decreases for the drier scenarios (WD and HD) of less than 10 percent for the 2030s and 10 to 20 percent for the 2070s, with a central tendency scenario showing more modest increases than the wetter scenarios. For mean Upper Klamath Lake supply (end-of-February storage plus March-September inflow), again the wetter scenarios indicate projected increases, with greater increases for the 2070s, while drier scenarios indicate decreases. Similar results are shown for mean Klamath Project supply from April through

September. Percent change in Upper Klamath Lake supply and Klamath Project supply (the bottom two measures listed in Figure 5-11) is computed based on projected and historical simulated values under the 2013 BiOp management criteria. No consistent differences are apparent in comparing CMIP3- and CMIP5-based scenarios. However, together they provide comprehensive information on the projected range of changes in these water delivery measures. Table 5-6 summarizes the data behind Figure 5-11.

### 5.4.3 Analysis of Impacts – Hydroelectric Power

To evaluate historical conditions and impacts of climate change on hydroelectric power production, the study focuses on the following measures: mean annual hydropower production (summed over J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities); mean annual spill volumes at J.C. Boyle, COPCO 1, and Iron Gate dams; and mean spill days per year at the same three dams. Measures are computed using results from the Klamath Basin RiverWare model.

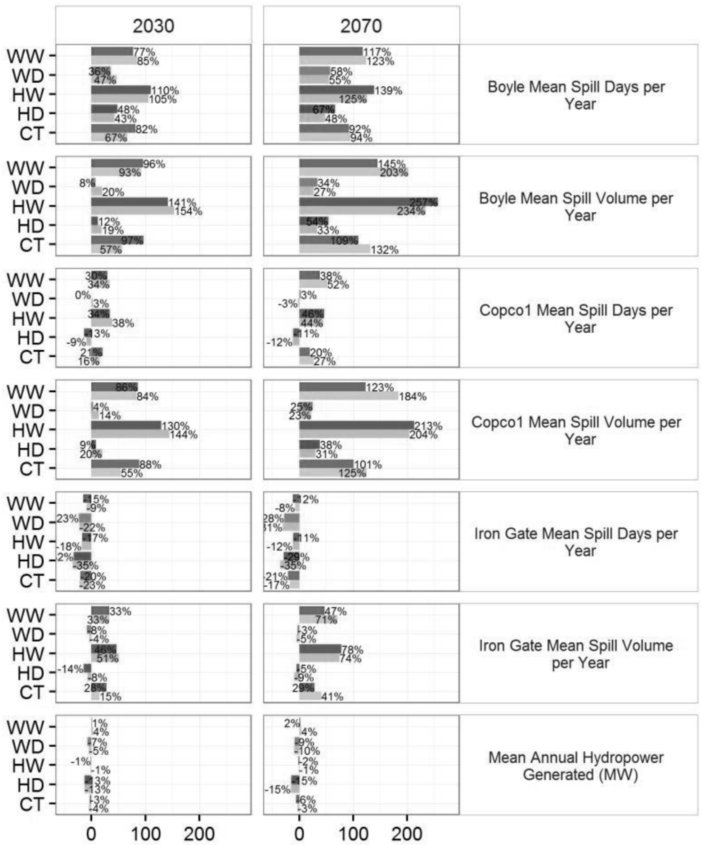
Historical hydropower measures are provided in Table 5-7, while projected changes in these measures are illustrated in Figure 5-12. Note that mean annual days with spill at the three facilities over the historical simulation period are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate.

**Projected Hydropower Production**

Hydropower production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. For all facilities, under almost all scenarios, frequency and volume of spill is likely to increase.

**Table 5-7. Historical measures related to hydroelectric power**

| Measure | Historical Value | Units |
|---|---|---|
| Mean annual hydropower generated (MW) | 26,741 | MW |
| J.C. Boyle mean spill volume per year | 163.0 | KAF |
| COPCO 1 mean spill volume per year | 186.4 | KAF |
| Iron Gate mean spill volume per year | 533.9 | KAF |
| J.C. Boyle mean spill days per year | 105.9 | days |
| COPCO 1 mean spill days per year | 42.8 | days |
| Iron Gate mean spill days per year | 170.3 | days |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-12. Projected changes in hydropower measures**

Figure 5-12 illustrates the percent change in identified hydroelectric power measures. Consistent with results discussed for basin-wide response variables, namely increased seasonal peak flows, the number of spill days and the mean annual spill volumes are projected to increase for most scenarios for both future time horizons. However, at Iron Gate the projected changes in spill volume are generally increasing, while the projected change in the mean number of spill days per year is less substantially decreasing. Projected mean number of spill days at J.C. Boyle and COPCO1 are generally increasing, while generally decreasing at Iron Gate. This result may be due to the fact that Iron Gate Reservoir has greater storage and is therefore better able to absorb high inflows than J.C. Boyle or

COPCO1. Also, the management criteria allow inclusion of a rule to avoid spill at Iron Gate, but not at J.C. Boyle or COPCO1, due in part to the need to meet environmental flow requirements.

Also, projected changes in mean annual hydropower production are much smaller on a percentage basis than the other measures, with the wetter scenarios indicating increases, the drier scenarios indicating decreases, and the central tendency scenario indicating minimal increases. Changes are between +4 percent and -13 percent for the 2030s and between +4 percent and -15 percent for the 2070s. Appendix D, Table D-12 summarizes the data behind Figure 5-12.

### 5.4.4 Analysis of Impacts – Recreation

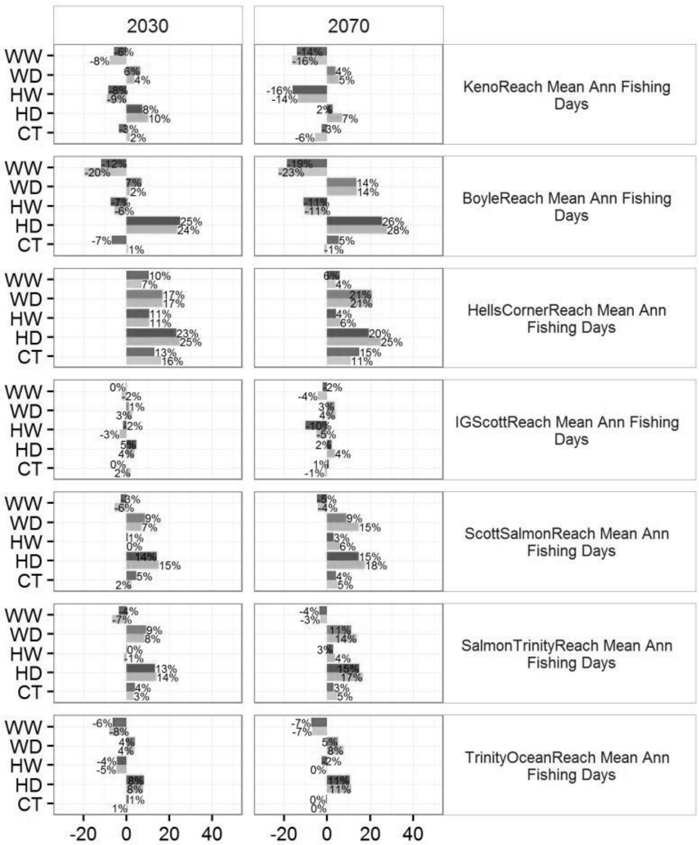
Recreational measures in the Klamath River Basin are summarized for two main categories, fishing recreation and river boating recreation. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in select Klamath River reaches fall within the recommended range for each activity. Measures are computed using results from the Klamath Basin RiverWare model.

> **Recreation**
>
> The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Table 5-8 provides historical recreation measures for fishing and river boating, while projected changes in these measures are illustrated in Figure 5-13 (for fishing) and Figure 5-14 (for river boating). For the historical period, in general more days fall within the recommended range for fishing than for river boating.

**Table 5-8. Historical measures related to fishing recreation**

| Measure | Historical Value | Units |
|---|---|---|
| Keno Reach mean annual fishing days | 248 | days |
| Boyle Reach mean annual fishing days | 155 | days |
| Hells Corner Reach mean annual fishing days | 220 | days |
| IG Scott Reach mean annual fishing days | 275 | days |
| Scott Salmon Reach mean annual fishing days | 184 | days |
| Salmon Trinity Reach mean annual fishing days | 214 | days |
| Trinity Ocean Reach mean annual fishing days | 253 | days |
| Keno Reach mean annual boating days | 172 | days |
| Boyle Reach mean annual boating days | 59 | days |
| Hells Corner Reach mean annual boating days | 256 | days |
| IG Scott Reach mean annual boating days | 275 | days |
| Scott Salmon Reach mean annual boating days | 249 | days |
| Salmon Trinity Reach mean annual boating days | 214 | days |
| Trinity Ocean Reach mean annual boating days | 253 | days |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-13. Projected changes in fishing recreation**

For fishing recreation, the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios (WW and HW) indicate decreases in the number of fishing days for both future time horizons. Recommended flows for fishing are generally less than for boating, and overall projections of greater future flow volumes in the basin correspond with projected decreases in fishing days. The central tendency scenario indicates modest decreases in some reaches and modest increases in other reaches. Generally, the direction of change (increase or decrease) is consistent for both future time horizons within a given reach (except J.C. Boyle reach and Trinity Ocean reach). For some scenarios and measures, CMIP3-based projections indicate greater

change, while for others they may indicate smaller change. There is no consistency between CMIP3- and CMIP5-based projections in terms of projected change across scenarios or measures.


Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-14. Projected changes in river boating recreation measures**

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. For instance, in the J.C. Boyle and Hells Corner reaches (from J.C. Boyle to COPCO 1) almost all scenarios indicate a decrease in the number of river boating days as a result of climate change, with the exception of the WW scenario for CMIP3 and the CT scenario for CMIP5. For the other reaches downstream of Iron Gate, the wetter

scenarios (WW and HW) generally indicate a reduction in the number of river boating days, while the drier scenarios (WD and HD) indicate increases in the number of river boating days (although not consistent for all measures). The CT scenario for those reaches below Iron Gate indicates modest changes (increases for most of those reaches). Note that the boating recreation measures do not account for the ability to release flows from J.C. Boyle to assure a suitable boating recreation flow range.

### 5.4.5 Analysis of Impacts – Ecological Resources

Measures related to ecological resources in the Klamath River Basin primarily concern fish and wildlife habitat and applicable species listed under ESA. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in the Scott and Shasta Rivers meet or exceed recommended flow thresholds for dry year conditions by McBain and Trush (2014). Note that the target flows were developed for the Shasta River and the same targets were applied to the Scott River, though the Scott River generally has greater flow volume. For this reason, the historical frequency of meeting flow targets in the Scott River is much higher than in the Shasta River. However, the dry year targets are not met 100 percent of the time in the Scott River.

Historical conditions and climate change impacts are also measured by computing watersupply to the Lower Klamath National Wildlife Refuge via Ady Canal. Measures are computed using results from the Klamath Basin RiverWare model.

**Ecological Resources Impacts**

The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. Also, a decrease in deliveries to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

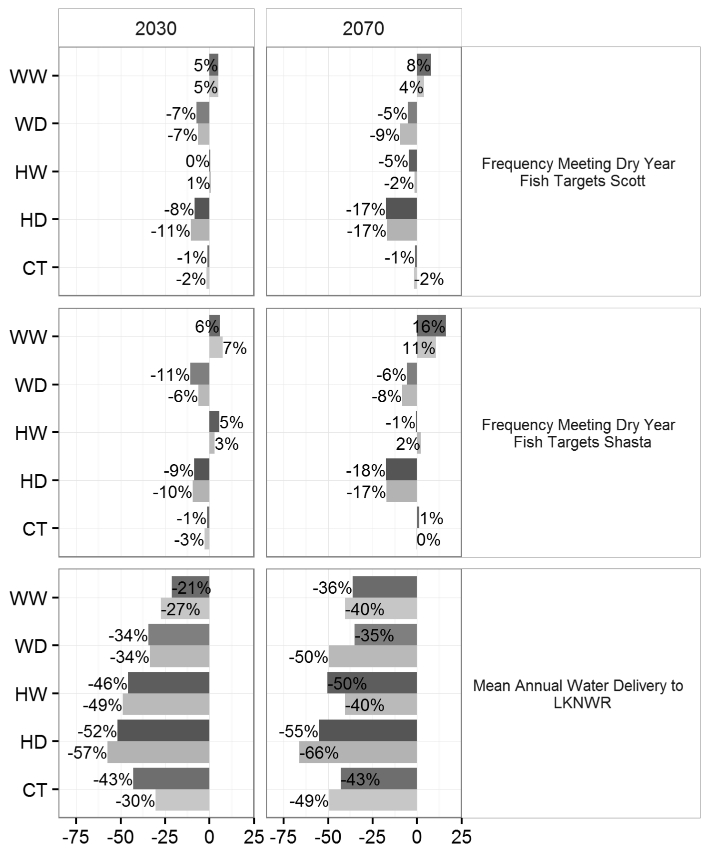
Historical measures relating to ecological benefits are provided in Table 5-9, while projected changes in these measures are illustrated in Figure 5-15. For the historical simulation period, neither dry year flow targets nor full demand at the LKNWR are met 100 percent of the time.

**Table 5-9. Historical measures related to ecological resources**

| Measure | Historical Value | Units |
|---|---|---|
| Frequency meeting dry year fish targets Scott | 70.5 | Percent of days |
| Frequency meeting dry year fish targets Shasta | 56.9 | Percent of days |
| Mean annual water delivery to LKNWR | 24.6 | KAF |

Projected changes in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers, represented as a percentage, indicate increases for

the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and HD), with greater change projected for the 2070s time horizon compared with the 2030s. CMIP3- and CMIP5-based projections are comparable, with one set of scenarios generally exhibiting more change (although not consistently one over the other). The CT scenario indicates a modest decrease in the frequency of ability to meet the dry year flow targets (i.e., negative change).




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-15. Projected changes in ecological resources measures**

Figure 5-15, illustrating the percent change in the mean annual (water year) supply to the LKNWR, shows that for all climate change scenarios there is a decrease in supply to the LKNWR, more so for the 2070s compared with the

2030s future time horizon. CMIP3- and CMIP5-based scenarios are comparable, but do show some differences. For the 2030s CT scenario, the CMIP5-based scenario indicates a reduction of about 43 percent, compared to 30 percent for the CMIP3-based CT scenario. Note that model results indicate a decrease in deliveries to LKNWR for all scenarios, while they indicate projected increases or decreases in Klamath Project supply depending on the scenario. These results may in part be explained by a projected reduction in water supply from the Lost River. Also note that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Additionally, the LKNWR is not able to take advantage of spill water under these management criteria. The resulting effect of the management criteria and projected hydrologic changes is an overall reduction in LKNWR deliveries.

Frequency of meeting minimum recommended pool elevations in Clear Lake and Gerber Reservoir were also computed as performance measures for evaluating climate change impacts. These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study. Note that climate change scenarios represent adjusted historical climates that represent the statistics of future climate for two future time horizons, the 2030s and 2070s. Therefore, potential changes in the timing and frequency of drier years and wetter years are not represented. Potential future changes in drought or wet period frequency may affect the ability of operators to maintain minimum pool elevations in Gerber Reservoir and Clear Lake.

**Water Quality Impacts**

For historical hydrology conditions and all future climate scenarios, the MWAT falls within the “poor” classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

### 5.4.6 Analysis of Impacts – Water Quality

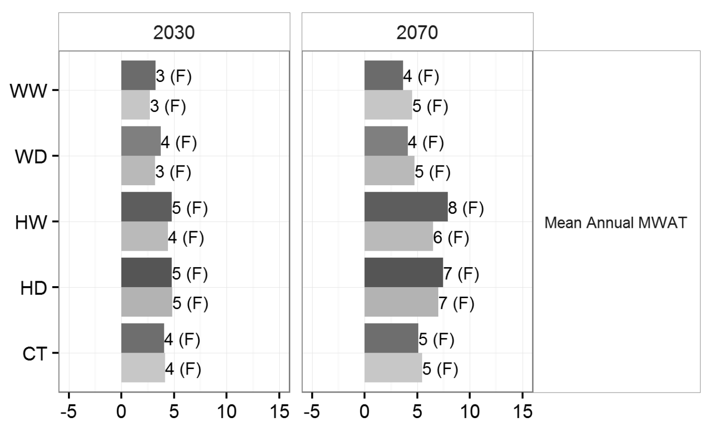
Water quality measures are presented in terms of meeting Klamath River temperature thresholds in the Klamath River near Klamath, California as recommended by the SONCC ESU salmon recovery plan (NMFS, 2012). Historical conditions and climate change impacts are evaluated by computing the mean across the simulation period of the MWAT at the Klamath River near Klamath and comparing values with those recommended in the salmon recovery plan. Analysis under historical hydrology showed that the MWAT fell within the “poor” classification for all years. Therefore, instead of reporting the frequency of the MWAT falling within the various categories ranging from “very good” to “poor,” we instead report the computed MWAT and projected change in that value, as well as the degrees F by which the “poor” classification is exceeded. The “poor” classification threshold is 63.68 degrees F, or 17.6 degrees C.

Historical measures relating to water quality are provided in Table 5-10, while projected changes in these measures are illustrated in Figure 5-16. Historically the MWAT is computed as 75.7 degrees F, which is approximately 12 degrees higher than the "poor" classification threshold for the SONCC ESU coho salmon.

**Table 5-10. Historical measures related to water quality.**

| Measure | Historical Value | Units |
|---|---|---|
| Mean annual MWAT | 75.7 | degrees F |
| Mean exceedance of MWAT – Poor | 12.1 | degrees F |

Figure 5-16 shows that for all climate change scenarios the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s. Results indicate that the temperature regime in the Klamath River is likely to become more challenging for coho salmon under warmer future climate scenarios. Identified cold water refugia and groundwater springs will continue to be critical for the survival of the species in the Klamath River Basin.




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-16. Projected changes in mean annual maximum weekly average temperature**

### 5.4.7 Analysis of Impacts – Flood Control

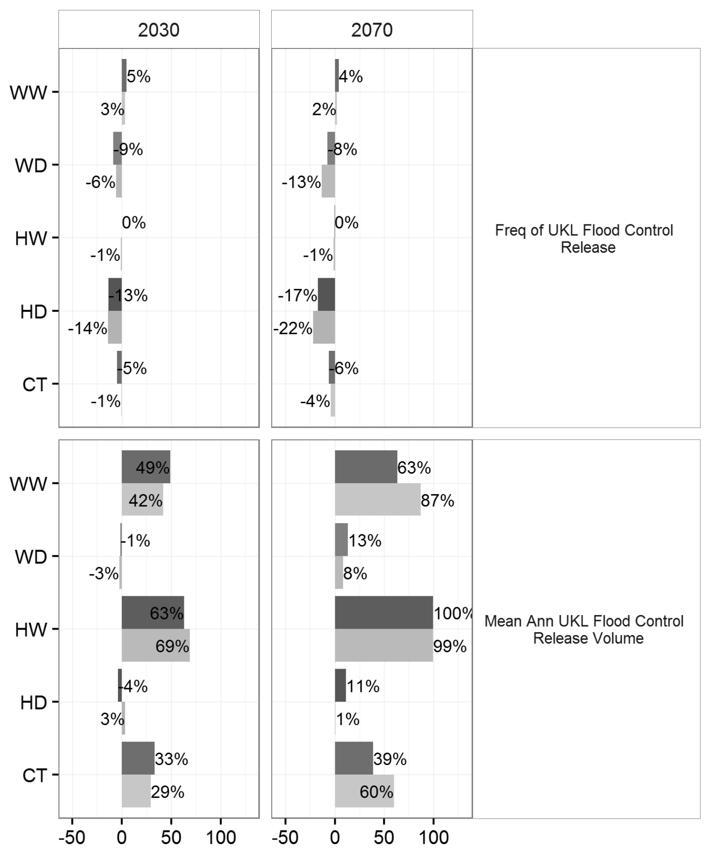
Flood control in the Klamath River Basin and projected changes due to a changing climate are evaluated for two types of measures: flood control releases from Upper Klamath Lake, and the date of seasonal peak flow at the major mainstem Klamath River dams (J.C. Boyle, COPCO 1, and Iron Gate). Flood control rules at Upper Klamath Lake are defined by the 2013 Proposed Action for Klamath Project Operations (Reclamation, 2012d). It is recognized that flood control measures exist for other reservoirs in the Klamath River Basin (e.g., Trinity River basin); however, due to the level of detail of the Klamath Basin RiverWare model, we focus on Upper Klamath Lake.

> **Flood Control Impacts**
>
> The frequency of Upper Klamath Lake flood control releases is projected to increase for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest increase. All scenarios project an increase in the mean annual flood control volume.

Historical recreation measures relating to flood control are provided in Table 5-11, while projected changes in these measures are illustrated in Figure 5-17. Under historical hydrology conditions, the frequency of flood control releases from Upper Klamath Lake is approximately 44 percent of days according to results from the Klamath Basin RiverWare model. The corresponding mean annual volume of flood control release water is approximately 224,000 acre-feet. Flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. The computations are consistent between the RiverWare model and the KBPM. However, it is acknowledged that the RiverWare model simulations generally indicate greater flows coming from the Lost River basin, thereby resulting in less demand by the Klamath Project for Upper Klamath Lake water, compared with the KBPM. This result may contribute to the seemingly high percentage of days of flood control release from Upper Klamath Lake. Greater flows from the Lost River basin may also explain some of the higher Keno Dam inflows in the winter time (refer to Figure 5-3). Future development of the model will further investigate these issues. The date of seasonal peak flow is the date of the center of mass of mean annual flow, or the average date by which half of the annual flow volume at the location has passed through. The historical seasonal peak flow at the three reservoirs mentioned ranges from early to mid-April.

**Table 5-11. Historical measures related to flood control**

| Measure | Historical Value | Units |
|---|---|---|
| Frequency of UKL Flood Control Release | 44.1 | Percent of Days |
| Mean Ann UKL Flood Control Release Volume | 224 | KAF |
| Date of Seasonal Peak Flow at J.C. Boyle Reservoir | April 9 | Date |
| Date of Seasonal Peak Flow at COPCO 1 Reservoir | April 17 | Date |
| Date of Seasonal Peak Flow at Iron Gate Reservoir | April 15 | Date |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-17. Projected changes in flood control measures**

Figure 5-17 shows that the frequency of Upper Klamath Lake flood control releases is projected to increase or change minimally for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. Again, CMIP3- and CMIP5-based projections are generally consistent. Although there is a projected decrease in the frequency of flood control releases for several scenarios, the figure also shows that all scenarios show a projected increase in the mean annual flood control volume. Further, more water is being released in the future even though the occurrence of release may be decreasing. Minimal projected change in Upper Klamath Lake flood control release, along with projected increases in spill volumes at J.C. Boyle and COPCO1 (refer to Figure 5-12), may be explained by the different ways spill is accounted for at these locations. At Upper Klamath Lake, spill is considered the volume beyond that released for Klamath Project deliveries and environmental needs, whereas at the other locations it is more simply computed as the volume above which water can be released through the power facilities. Management criteria also play a role in the differing results.

The projected change in the date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate dams ranges from little or no change to a shift toward an earlier peak by as many as 17 days (HW scenarios for CMIP3 and CMIP5 for the 2070s future time horizon). For the 2030s, the CT scenario indicates a shift toward earlier in the year by up to one week at COPCO 1 and Iron Gate, while for the 2070s the projected change for the CT scenario is about 7 to 10 days earlier. In general, projected changes in the date of seasonal peak flow at J.C. Boyle are less substantial than at the other two locations evaluated, with projected changes having ranging from 1 to 4 days later for the 2030s, and 4 days earlier to 3 days later for the 2070s depending on the scenario. Table D-13 in Appendix D summarizes the results for all scenarios and time periods.

## 5.5 Summary of Findings

This chapter evaluates the ability of the basin to meet historical and projected future water needs using a framework of models and associated measures that are used to quantify vulnerabilities. Simulations (with historical and future hydrology conditions) were performed using existing operational constraints, mainly associated with the current Proposed Action for Klamath Project operations (Reclamation, 2012d), which dictate operations throughout the Upper Klamath Basin and have implications for the river from Link River Dam to its mouth.

Performance measures for selected categories provide a basis for assessing two things: first, the ability of the modeling framework to identify and evaluate vulnerabilities to meeting the basin's water needs, and second, the ability to evaluate the impacts of climate change on the watershed. The results provide useful insights as to how climate changes, without adaptation responses, impact the Klamath Basin. The following paragraphs summarize the above analysis of managed historical and projected future conditions.

Analysis of climate change impacts using the Klamath Basin RiverWare model and USGS RBM10 water temperature model show that mean EOM storage in Upper Klamath Lake will experience earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, EOM reservoir storage historically did not fluctuate substantially through the year. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase slightly. Projections of mean monthly managed flows at various locations throughout the study area indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

Figure 5-2 showing simulated historical and projected UKL storage helps to illustrate the projected change. The simulations show historical peak storage around May. Projections indicate a shift toward earlier peak storage. In addition, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although none of the figures illustrate UKL inflow, it appears that Project supply is projected to decrease slightly for the drier scenarios and increase slightly for the wetter scenarios, with a small increase for the central tendency scenario. Therefore, any reduction in summer UKL inflow does not appear to affect Project supply by a large amount, on average.

Historical hydrology enables an annual average of 93 percent of full delivery to Klamath Project irrigation, according to simulations by the Klamath Basin RiverWare model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Hydropower production summed for the J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities has historically been about 26,800 MW, according to RiverWare model simulations. Production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. We evaluated frequency and volume of spill at J.C. Boyle, COPCO 1, and Iron Gate dams and found that historically the dams spilled an average of 106 days at J.C. Boyle, 43 days at COPCO 1, and 170 days at Iron Gate per year. For all facilities, frequency and volume of spill is likely to increase with climate change.

Historical fishing and boating recreation in the Klamath River Basin has been strong (on the order of 155 to 275 fishing days per year and 59 to 275 river boating days per year). The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Using flow recommendations for a dry year in the Shasta River (defined as 61 to 100 percent exceedance) from McBain and Trush (2014), we found that flow

targets were met historically on an average of 57 percent of days in the Shasta River and 71 percent of days in the Scott River (which has about three times the mean annual flow of the Shasta River). The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. In the future, a decrease in water delivery to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

For historical conditions and all future scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

Finally, according to the Klamath Basin RiverWare model, the historical frequency of flood control releases from Upper Klamath Lake has been about 44 percent of days, with a mean volume of about 224,000 acre-feet. The frequency of these releases is projected to increase or show little change for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. All scenarios project an increase in the mean annual flood control volume. The date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate has historically been early to mid-July, according to the model simulations. Projections of future conditions show a general shift of this peak toward earlier in the year, although the degree to which this is the case varies by scenario and location. The most modest changes are projected for J.C. Boyle (on the order of 4 days later to 3 days earlier for the 2070s). Greater shifts are projected for COPCO 1 and Iron Gate, on the order of 1 day later to 9 days earlier for the 2030s and 2 to 16 days earlier for the 2070s.

Results of the system risk and reliability analysis support the common understanding that the Klamath River Basin has experienced difficulties in meeting the range of water needs. Projected increases in precipitation and flow volumes at many locations in the basin may reduce water supply gaps in some ways; however, greater challenges are projected for ecological resources such as fish and wildlife, as well as irrigators in the Upper Klamath Basin.

## 5.6 Uncertainties Associated with System Reliability Analysis

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study system risk and reliability analysis. The uncertainties primarily correspond to the modeling used to evaluate historical and future conditions. The modeling framework for this analysis includes development and implementation of the Klamath Basin RiverWare model, as well as implementation of the USGS RBM10 water temperature model for the mainstem Klamath River. Uncertainties associated with each of these modeling efforts are

identified and described below. Further discussion of uncertainties associated with the Klamath Basin RiverWare model will be presented as part of a separate technical report documenting the development of the model.

The Klamath Basin RiverWare model was developed as a basin-wide tool for simulating current operations under the 2012 Proposed Action for Klamath Project operations (Reclamation, 2012d). Operating rules for the Proposed Action were translated from the original modeling platform of the Klamath Basin Planning Model into RiverWare. Because the KBPM modeling platform differs from the RiverWare platform, management rules in some instances were modified to accommodate the RiverWare platform. Calibration of the RiverWare model, using historical data consistent with KBPM data, was performed to the best of our ability. However, differences persist between historical hydrology-driven model simulations using the KBPM and the RiverWare models. Model calibration will continue to be addressed in the future as the model is applied to future projects.

The USGS RBM10 water temperature model was used in its original form as part of the Basin Study. Historical inputs consistent with the Basin Study water supply and demand assessments were used as input to the RBM10 model to maintain consistency within the Basin Study. Many of these inputs differed from those used in the original implementation of the RBM10 model for the dam removal studies. As such, we employed a bias correction technique for the meteorological data so it better represented the statistics of the original model data. This also facilitated use of the model in the Basin Study because, under this methodology, it was not necessary to recalibrate parameters of the water temperature model.

Simulated managed streamflows at boundary locations used by the RBM10 model were provided by the Klamath Basin RiverWare model. Original development of the RBM10 model used USGS gage data for these boundary inputs. Historical simulated RiverWare model output was, as expected, different from the inputs for the original model. Within the RiverWare model, it was possible to experience negative or close to negative flows in certain river reaches due to river routing and the computation of reach gains. The RBM10 model cannot compute water temperature provided negative river flows, so a 5 cfs adjustment was made to simulated boundary flow for those timesteps where negative flows occurred.

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# Chapter 6
# Klamath River Basin Study
# Evaluation of System Reliability with Strategies

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



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# Chapter 6 Evaluation of System Reliability with Strategies

## 6.1 Introduction

Chapter 6 presents the process that was developed and utilized to formulate and screen adaptation strategies for reducing identified gaps between water supply and demand. It also identifies the strategies carried forward for quantitative evaluation under the framework developed for the Basin Study, which is further described in Chapter 5, System Risk and Reliability Analysis. Figure 6-1 provides an overall schematic of the Basin Study approach.

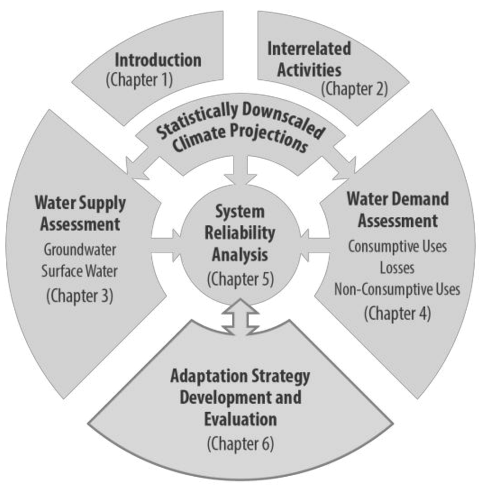


**Figure 6-1. Overall approach of Klamath River Basin Study, highlighting Chapter 6**

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## 6.2 Formulation of Adaptation Strategies

The overall approach for formulating adaptation strategies to be evaluated in the Klamath River Basin Study includes the following steps:

- Identify strategies that cover a range of options.
- Organize proposed strategies in general categories based on their primary function.
- Characterize strategies based on a set of criteria to facilitate strategy screening.
- Develop representative options that allow for simplified analysis and that avoid redundancy.

Each of these approach steps is further described below.

### 6.2.1 Approach to Adaptation Strategy Identification

Adaptation strategies were identified through a comprehensive literature review of studies on climate change and water supply issues specific to the Klamath River Basin as well as studies focused on the broader Pacific Northwest. In addition to this literature review, the Basin Study team completed outreach to Klamath River Basin agency representatives, tribal representatives, stakeholders, and residents through conference calls, attendance at water supply management and planning meetings in the basin, and outreach through the Basin Study website.

The literature review effort identified 49 reports, studies, agreements, doctoral dissertations, and masters' theses completed by federal and state resource agencies, tribal natural resource departments, and university researchers. From this literature review and stakeholder input, 185 unique adaptation strategies were identified and carried forward for evaluation in the screening process described below. The full list of identified adaptation strategies is presented in Appendix E.

#### *6.2.1.1 Organization of Proposed Adaptation Strategies*

The adaptation strategies were divided into categories to facilitate a comparison of the strategies with similar approaches to addressing water supply and demand changes. These categories – increase supply, decrease demand, modify operations, and governance and implementation – are each populated with multiple strategies. This same general approach was used for the Colorado River Basin Water Supply and Demand Study (Reclamation, 2001e). The four general categories are further described below:

> ***Increase Supply:*** This category encompasses strategies that result in an anticipated increase in water supply or that identify alternative water supplies. Strategy examples include creating groundwater recharge

opportunities, increasing surface storage capacity, increasing the use of recycled water, developing conjunctive use programs, and implementing vegetation management actions.

***Decrease Demand:*** This category encompasses strategies that result in an anticipated decrease in water demand either directly or indirectly. Strategy examples include M&I water conservation (direct reduction), agricultural water conservation (direct reduction), energy water use efficiency (indirect reduction), and reductions in environmental demand (direct reduction).

***Modify Operations:*** This category encompasses strategies that involve alternative management decisions that may result in a change in water supply and/or demand. Strategy examples include improving infrastructure reliability and efficiency, reducing hillslope and/or bank erosion, improving water quality, improving preparedness for extreme events, reducing reservoir and lake evaporation, reducing out of basin transfers, improving intra-regional water transfers, or improving operational flexibility.

***Governance and Implementation:*** This category encompasses strategies that involve changes in policy, management, legal structure, or future governance issues in the Klamath River Basin. Strategy examples include improvements to public education, developing and improving partnerships between stakeholders, improving research, modifying or developing new policies, developing decision support tools, providing for habitat protection, seeking funding, implementing watershed management, and improved land use practices.

Figure 6-2 indicates the number of proposed adaptation strategies identified per category.

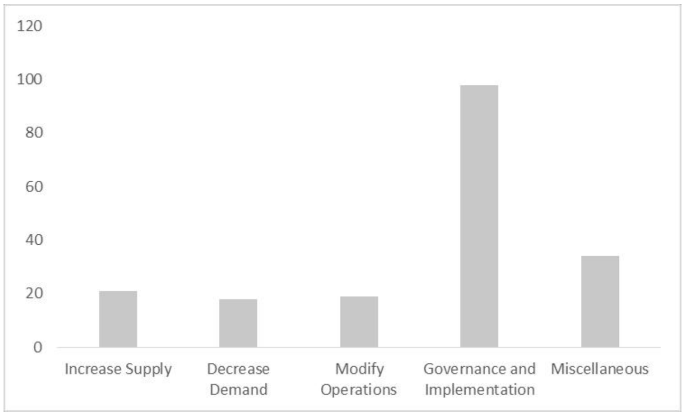



**Figure 6-2. Number of adaptation strategies identified**

#### *6.2.1.2 Criteria for Adaptation Strategy Screening*

Once the proposed strategies were organized into general function categories, they were evaluated and screened in a staged analysis effort. Evaluation measures were utilized to assess each adaptation strategy's capacity to address changes in water supply and demand. These evaluation measures were developed by Reclamation in consultation with the non-federal partners consistent with the selection criteria developed for the evaluation of options during development of the On Project Plan (Klamath Water and Power Agency, 2013). The On Project Plan screening criteria were formulated through an extensive stakeholder outreach process that resulted in wide acceptance of their use for the screening of the water conservation and efficiency, water storage, groundwater development and substitution, and demand management options identified in that planning effort. Reclamation and the non-federal partners relied on these widely accepted criteria during the development of evaluation measures for the Basin Study to incorporate the input already provided by these stakeholders.

The initial screening effort evaluated each strategy in each category to determine if it could be represented by the Basin Study models. Strategies that could be modeled could be quantitatively evaluated in this Basin Study Report; strategies that could not be modeled were evaluated qualitatively. The results of the first screening for each strategy are included in Appendix E.

Following the initial screening, the strategies that could be modeled were evaluated qualitatively, utilizing the criteria detailed below in Table 6-1, to assess the strategy's implementation risk and uncertainty, reliability, and environmental effect. Reclamation and the non-federal partners qualitatively evaluated these screening criteria, arriving at representative strategies that encompass the collective goals of the criteria, present the greatest potential for beneficial effect, and were identified as high priorities to the non-federal partners, while also involving a range of options for reducing identified vulnerabilities in the Klamath River Basin.

**Table 6-1. Description of criteria for assessing adaptation strategies**

| |
|---|
| **Provides verifiable, durable and implementable benefit to align water supply and demand for the Klamath River Basin** |
| This criterion evaluates whether a strategy is capable of providing verifiable and affordable reductions in projected water supply/demand gaps and assures all associated administrative requirements are reasonable and not overly burdensome or complex. Strategies performing well under this criterion are expected to provide a measurable water supply increase, and strategies with low ratings are anticipated to deliver minimal increases in water supply that would be difficult to verify. |
| **Consistency with legal and regulatory requirements** |
| This criterion evaluates whether a strategy is implementable with respect to compliance with all existing laws, regulations, or contracts, or requires a relatively minor revision in such requirements that would allow for implementation. Strategies that performed well under this criterion had no identified legal and regulatory issues and strategies with low ratings would require major legal or regulatory actions, like new water rights and major environmental compliance investigations. |

**Table 6-1. Description of criteria for assessing adaptation strategies**

| |
|---|
| **Affordability** |
| This criterion evaluates whether a strategy furthers the objective of aligning demand with Klamath water supply availability in a manner that is commensurate with the cost, allowing for a comparison of the relative cost of alternative strategies. This criterion was rated with high ranking strategies requiring no new costs or investment and low performing strategies requiring large capital expenditures and/or high long-term operations and maintenance costs. |
| **Flexibility** |
| This criterion evaluates whether a strategy would have, or not unduly limit, the capability to be adjustable over time. This criterion was rated with high ranking strategies allowing for implementation to be adjusted over time and low ranking strategies implementing new infrastructure that could not be moved or have its operations modified. |
| **Protection of water rights** |
| This criterion evaluates whether a strategy would result in injury to existing water rights holders. This criterion was rated with high ranking strategies producing no effect on existing water rights and low ranking strategies potentially impacting neighboring surface and groundwater availability. |
| **Environmental and third-party impacts and benefits** |
| This criterion evaluates whether a strategy would comply with applicable environmental laws and not involve unacceptable environmental impacts. This criterion was rated with high ranking strategies producing no effect on environmental resources and low ranking strategies generating adverse impacts on water quality and other resources. |

#### *6.2.1.3 Summary of Selected Adaptation Strategies*

The adaptation strategy screening process resulted in the identification of five strategy concepts that are carried forward for evaluation in the Basin Study models. This section summarizes these strategy concepts by category.

**Increase Supply**

*Additional Surface Water Storage Capacity*

This strategy concept includes quantification of potential surface storage opportunities in the Upper Klamath Basin. Some examples of proposals that fall within this strategy concept are listed in Appendix E. Additional surface water storage capacity is quantified as the incremental excess water defined in the Klamath Basin Planning Model. This excess water is quantified as the remaining water after releases are made to the Klamath Project and to meet environmental needs, including instream flow needs in the Klamath River and water stored in Upper Klamath Lake to maintain elevations. For this strategy, it is assumed that the remaining water could be stored for future use; however, it is acknowledged that the 2013 Klamath Project proposed action Biological Assessment and associated Biological Opinion consider this quantity to be part of the environmental water account.

**Decrease Demand**

*Agricultural Water Conservation*

This strategy concept includes reduction in overall agricultural water demand throughout the basin by a range of percentages (between 30 percent and 50 percent). One goal of this implemented strategy concept is to determine how

much reduced agricultural demand would be needed to offset the impacts of climate change alone. Reductions in agricultural water demand might be obtained through means identified in the proposed strategy examples listed in Appendix E. These might include canal lining and pump operation optimization; crop idling, irrigated land retirement and rain-fed agriculture; shifting agricultural production to more drought tolerant crops; and converting irrigation systems to more efficient technologies along with the use of cover crops to improve soil productivity.

*Additional Supply to Upper Klamath Lake*
This strategy concept captures the additional 30,000 acre-feet of water provided for Upper Klamath Lake in the KHSA, KBRA, and Upper Klamath Basin Comprehensive Agreement as generated by land retirement actions in the Upper Klamath Basin. The strategy concept does not identify individual areas where water demand reduction would occur. However, this strategy assumes that the additional volume of water is made available proportionally between the Sprague River, the Williamson River upstream of its confluence with the Sprague River, and the local inflows between the confluence and Upper Klamath Lake. The proportions of the total 30,000 acre-foot volume are determined based on the relative contributions to Upper Klamath Lake inflows of mean annual flow from these three sources (Sprague River, Williamson River, and local inflows between the Sprague-Williamson confluence and Upper Klamath Lake). The goal of this strategy concept is to evaluate the effect of reductions in collective water use upstream of Upper Klamath Lake. This strategy also assumes that operating rules are not modified to compensate for the additional Upper Klamath Lake inflow.

**Modify Operations**
Two strategy concept options were developed to capture the adaptation strategy articulated in the screening process as “reduce environmental demand.” These strategy concepts were developed to facilitate the analysis in the Basin Study models of five strategy examples: protect cool water refugia; keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes; purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis; curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs; and ensure adequate flows for fish and wildlife habitat.

*Tributary Water Temperature Reduction*
This strategy concept addresses the need for cold water refugia in summer months to support fish and wildlife, particularly salmonids, in the Klamath River Basin tributaries. This concept is based on existing emergency water management planning in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs. In this strategy concept, a 4 degrees Celsius (degrees C) reduction in water temperature (or about 7 degrees F) in the Scott and Shasta Rivers is assumed as input to the RBM10 stream temperature model for the Klamath River, and effects of that reduction on mainstem Klamath River temperature are evaluated.

#### *6.2.1.4 Sensitivity of Simulated Water Temperature to Changes in Flow and Climate*

This strategy concept includes exploring relationships between water temperature change and streamflow change, using historical and future climate change simulations of managed streamflow (using the Klamath RiverWare planning model) and river temperature (using the RBM10 model). By evaluating potential relationships between temperature and flow change, it may be possible to estimate the needed change in flow to obtain a desired change in Klamath River temperature. Such information may be valuable in determining what changes in water management may be needed to counter the impacts of climate change.

## 6.3 Uncertainties Associated with Strategy Selection

Adaptation strategies were intended to encompass a range of management actions. They were selected to be broad in scope with basin-wide implications, and not specific to any particular subbasin or singular project operation. Broad strategy concepts were selected, in part because numerous existing studies have evaluated some proposed actions in depth, and also because management conditions in the basin are dynamic. Strategies were selected with the intent that they noticeably reduce water supply and demand imbalances; however, they were selected without prior knowledge of their relative impact. Therefore, there is uncertainty as to whether the selected strategies have greater impact on system reliability than those that were not selected. In short, there may be additional strategies that could reduce water supply and demand imbalances but were not considered by the study.

In addition, strategies were initially screened on their ability to be modeled in the framework of the Basin Study. A strategy that could not be modeled by the Basin Study framework may in fact have substantial impact on system reliability; however, the impact could not be appropriately assessed with respect to that resulting from selected strategies.

## 6.4 Evaluation of System Reliability with Adaptation Strategies

In Chapter 5, projected response to climate change is evaluated by examining effects on basin-wide response measures and on several categories of performance measures. Basin-wide response measures include flows at key locations, river temperature, UKL storage, and Project delivery. Performance measures provide additional details on operational elements such as hydropower, flood control, recreation, and ecological resources. In the analysis described in Chapter 6, the potential for adaptation strategies to affect response to climate change is evaluated. Basin-wide response measures and system performance measures are examined, comparing the collective effects of both climate change and adaptation strategies to the effects of climate change alone.

An illustration of the model scenarios that capture these differences is visualized in Figure 6-3. The baseline scenario uses historical hydrology, and in Chapter 5 we compare results from model simulations using five future climate scenarios, for both the 2030 time horizon and the 2070 time horizon, as well as CMIP3- and CMIP5-based temperature and precipitation projections. The blue line in Figure 6-3 demonstrates this comparison. In this chapter (Chapter 6), the focus is on the effects depicted by the orange line and how these differ from the baseline comparison.

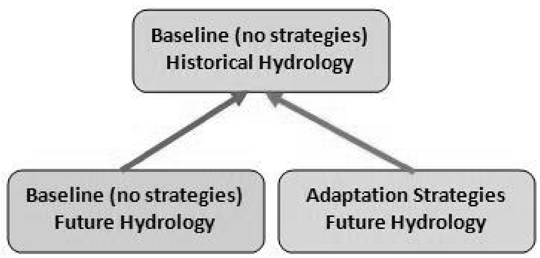



**Figure 6-3. Illustration of methodology for evaluating adaptation strategy concepts**

The following sections summarize projected changes in basin-wide response variables and system performance measures according to the baseline (i.e., with climate change scenarios but no adaptation strategy concepts) and adaptation strategy concepts previously discussed. Summary figures throughout this section illustrate changes in the strategy concepts associated with agricultural water conservation and additional supply to Upper Klamath Lake. The strategy concepts are defined as follows in the summary figures:

**Baseline** – with climate change impacts, but no adaptation strategy concepts. This is similar in concept to a no action scenario.

**Reduce ET 30% -** Reduction of agricultural demands throughout the basin by 30 percent

**Reduce ET 50% -** Reduction of agricultural demands throughout the basin by 50 percent

**Add 30KAF** – Addition of 30 KAF annually to Upper Klamath Lake inflow (contributed proportionally by Williamson River, Sprague River, and other gains, based on mean annual flow)

Results for additional strategy concepts are summarized for water quality measures. These additional strategy concepts are defined as follows in the summary figures under Section 6.4.6, Analysis of Impacts – Water Quality. Note

that this adaptation strategy concept only affects the water quality measures. Therefore, results for this measure are only summarized for these measures.

**Reduce Shasta Scott 4degC** – Reduction of Shasta and Scott River temperatures by 4 degrees C (about 7 degrees F) year round

**Add Flow 10% -** Addition of flow by 10 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

**Add Flow 20% -** Addition of flow by 20 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

**Reduce Tribs 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round in all tributaries represented in the RBM10 water temperature model. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

**Reduce Dam Outflow 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Results for the strategy concept to quantify additional surface water storage capacity are summarized under Section 6.4.7, Analysis of Impacts – Flood Control, where the mean annual Upper Klamath Lake flood control volume is quantified and evaluated. This strategy concept does not identify any specific location for additional surface water storage; however, the location for quantifying additional water is at Upper Klamath Lake.

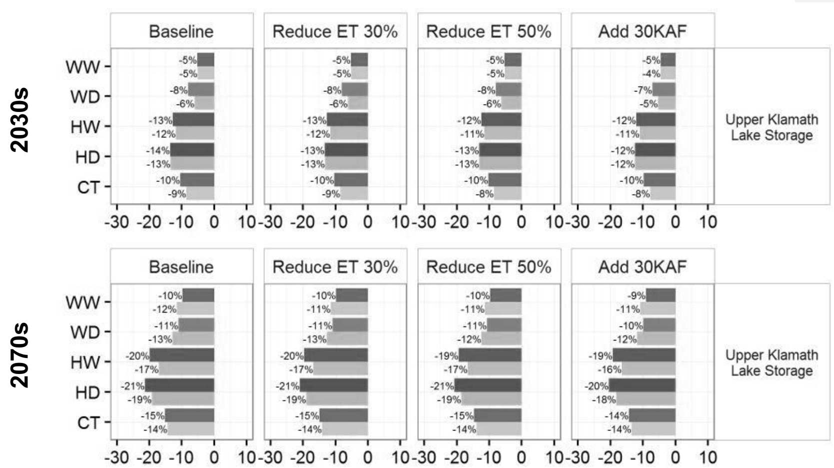
### 6.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of system reliability under baseline and scenarios with adaptation strategy concepts allows for an understanding of how strategies may reduce the basin's vulnerability to climate change. Similar to Chapter 5, we explore projected change in managed river flow at various locations within the basin, as well as mainstem Klamath River stream temperature.

#### *6.4.1.1 Upper Klamath Lake Storage*

Projected changes in mean annual end of month (EOM) storage in Upper Klamath Lake under baseline and strategy scenarios are summarized in Figure 6-4. Under the baseline scenario (climate change only), mean annual storage is projected to decline under all scenarios, more so for the 2070s than for the 2030s. Neither of the strategy concepts for reducing agricultural water demand (by 30 percent and 50 percent) reduce climate change impacts substantially. Percent reductions in storage conditions are minimally affected, except for the HD climate change scenario for the 2030s and for the warmer scenarios (WW and WD) for the 2070s.

Adding 30 KAF of inflow to Upper Klamath Lake does reduce the impacts of climate change by 1 to 2 percent under all climate change scenarios for both the 2030s and 2070s. Table 6-2 summarizes projected changes in storage volume under the CT scenario for both future time periods. Implementing the Add 30KAF strategy concept results in a 26 or 33 KAF reduction in mean annual storage for the 2030s, compared to 29 or 35 KAF for the baseline for CMIP3- and CMIP5-based projections, respectively. For the 2070s, the projected reduction is 46 or 48 KAF, compared to 48 or 51 KAF for the baseline.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

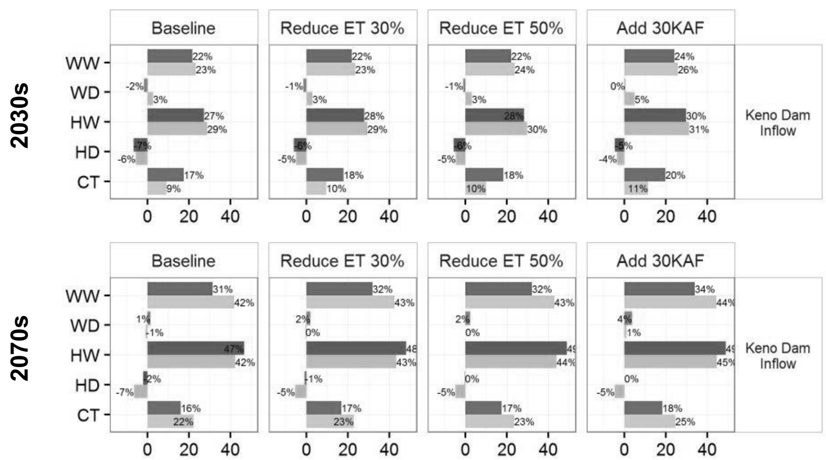
**Figure 6-4. Projected change (percent) in mean annual Upper Klamath Lake storage**

**Table 6-2. Summary of projected change in mean annual Upper Klamath Lake Storage for the Central Tendency scenario in units of KAF**

| Central Tendency Scenario | CMIP | Baseline (KAF) | Reduce ET 30% (KAF) | Reduce ET 50% (KAF) | Add 30KAF (KAF) |
|---|---|---|---|---|---|
| Historical | | 337 | | | |
| 2030 | CMIP3 | -29 | -29 | -28 | -26 |
| | CMIP5 | -35 | -35 | -34 | -33 |
| 2070 | CMIP3 | -48 | -47 | -47 | -46 |
| | CMIP5 | -51 | -50 | -50 | -48 |

#### *6.4.1.2 Keno Dam Inflow*

Projected changes in mean annual inflow to Keno Dam under baseline and strategy scenarios are summarized in Figure 6-5. Under the baseline scenario (climate change only), mean annual inflow is projected to increase under the wetter scenarios (WW and HW) for both future time periods and decrease modestly under the drier scenarios (WD and HD), with an increase under the CT scenario projected to be 9 or 17 percent for the 2030s and 16 or 22 percent for the 2070s, depending on consideration of CMIP3- or CMIP5-based projections. Implementation of each of the strategy concepts would maintain or increase the mean annual inflow at Keno, and by similar percentages. Addition of 30 KAF of inflow to Upper Klamath Lake appears to have a larger effect on Keno inflow than does reduction in agricultural demands in the regions upstream of Keno.



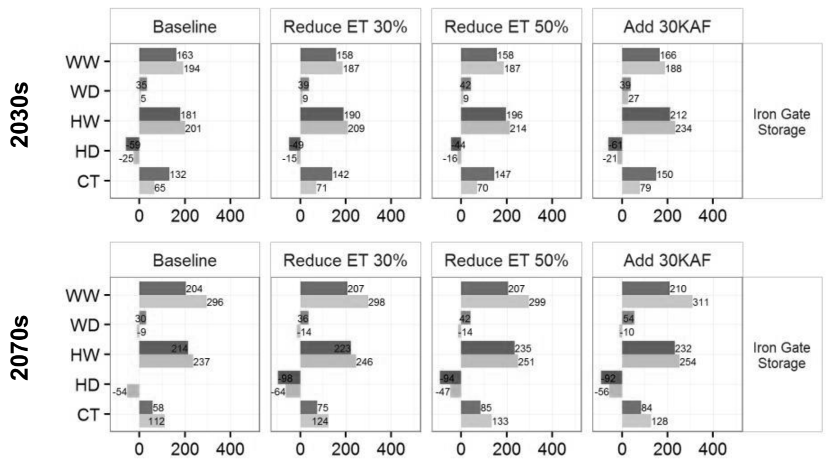

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-5. Projected change (percent) in mean annual inflow to Keno Dam**

#### *6.4.1.3 Iron Gate Reservoir Storage*

Projected changes in mean annual Iron Gate Reservoir storage under baseline and strategy scenarios are summarized in Figure 6-6. Under the baseline scenario (climate change only), mean annual storage is projected to change very little on a percentage basis compared with the historical simulation. Iron Gate Reservoir elevations have not fluctuated much historically, typically staying between 55,000 acre-feet and 57,000 acre-feet. Projected changes shown in Figure 6-6 are reported in units of acre-feet. Mean annual storage is projected to increase under all scenarios and strategies, with the exception of the HD scenario for both the 2030s and 2070s time periods. Reduction of agricultural demand provides some additional storage at Iron Gate, but generally the addition of 30 KAF inflow to Upper Klamath Lake has a larger impact on Iron Gate storage. Still, all

adaptation strategy concepts do not substantially change Iron Gate storage and do not generally counter the effects of climate change.

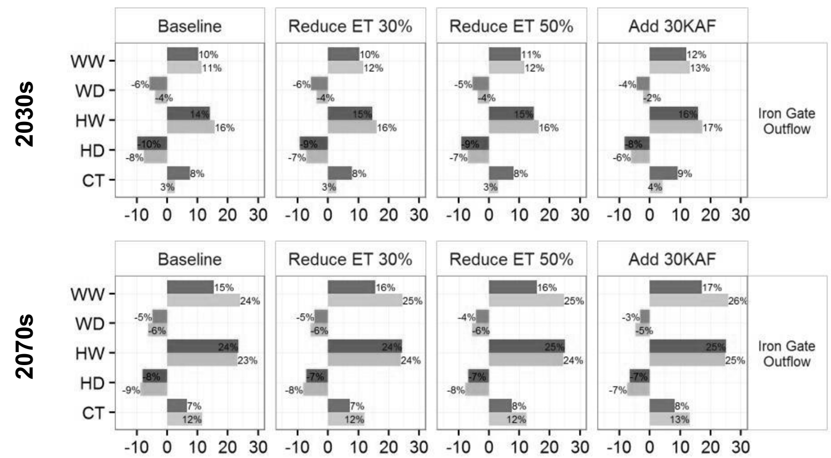



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-6. Projected change (acre-feet) in mean annual Iron Gate Reservoir storage**

#### *6.4.1.4 Iron Gate Reservoir Outflow*

Projected changes in mean annual Iron Gate Reservoir outflow under baseline and strategy scenarios are summarized in Figure 6-7. Under the baseline scenario (climate change only), mean annual outflow is projected to increase under wetter scenarios (WW and HW) and decrease modestly under drier scenarios (WD and HD), with the CT scenario indicating increases of 3 or 8 percent for the 2030s and 7 or 12 percent for the 2070s. Implementation of adaptation strategies does not substantially counter climate change impacts. Reduction of agricultural demand increases the effect of additional outflow at Iron Gate, but only by about one percent for most climate change scenarios considered. Additional inflow to Upper Klamath Lake (Add 30KAF) increases the additional outflow at Iron Gate by up to 2 percent over the baseline response to climate change alone.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-7. Projected change (percent) in mean annual inflow to Iron Gate Reservoir.**

#### *6.4.1.5 Shasta River Flow*

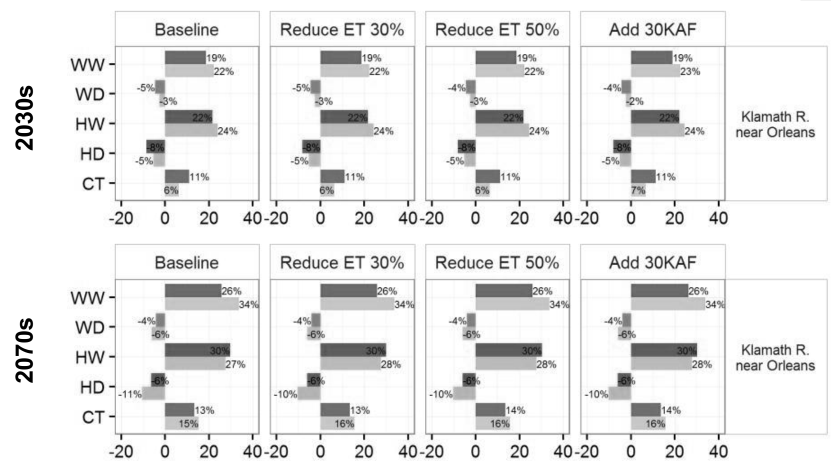
Projected changes in mean annual flow in the Shasta River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

#### *6.4.1.6 Scott River Flow*

Projected changes in mean annual flow in the Scott River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

#### *6.4.1.7 Flow at Klamath River near Orleans*

Projected change in mean annual flows in the Klamath River near Orleans under baseline and strategy scenarios is summarized in Figure 6-8. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 6 or 11 percent for the 2030s and 13 or 15 percent for the 2070s, according to model simulations. Similar to other upstream locations, reduction of agricultural demand in the contributing area to the basin upstream of Orleans results in no change for the 2030s and little change for the 2070s in simulated managed flow on a percentage basis. Additional Upper Klamath Lake inflow of 30 KAF annually has only a slightly greater impact than agricultural demand reduction.

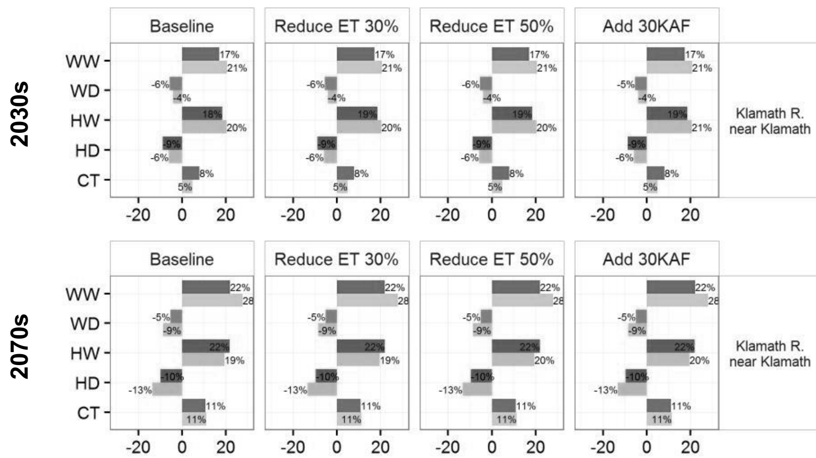



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-8. Projected change (percent) in mean annual flow at Klamath River near Orleans**

### *6.4.1.8 Flow at Klamath River near Klamath*

Projected changes in mean annual flows in the Klamath River near Klamath under baseline and strategy scenarios are summarized in Figure 6-9. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 5 or 8 percent for the 2030s and 11 percent for the 2070s, according to model simulations. Generally, the adaptation strategies either have no influence or increase flows on a mean annual basis, about one percent or less for the 2030s and no noticeable change for the 2070s. This result is in part due to the fact that any change in flow volume is a small percentage of the overall river flow at Klamath, which is close to the mouth of the basin.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-9. Projected change (percent) in mean annual flow at Klamath River near Klamath**

### 6.4.2 Analysis of Impacts – Ability to Deliver Water

As discussed in Chapter 5, measures of the ability of the Klamath River Basin to supply water to meet human needs include (1) the April through September irrigation water supply to the Klamath Project (Project Supply), (2) mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow (Upper Klamath Lake Supply), (3) mean annual flows in the Shasta River near Yreka, and (4) mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the historical simulation period, the Upper Klamath Lake Supply parameter was about 1.38 million acre-feet. Additional measures representing the overall hydrology conditions in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

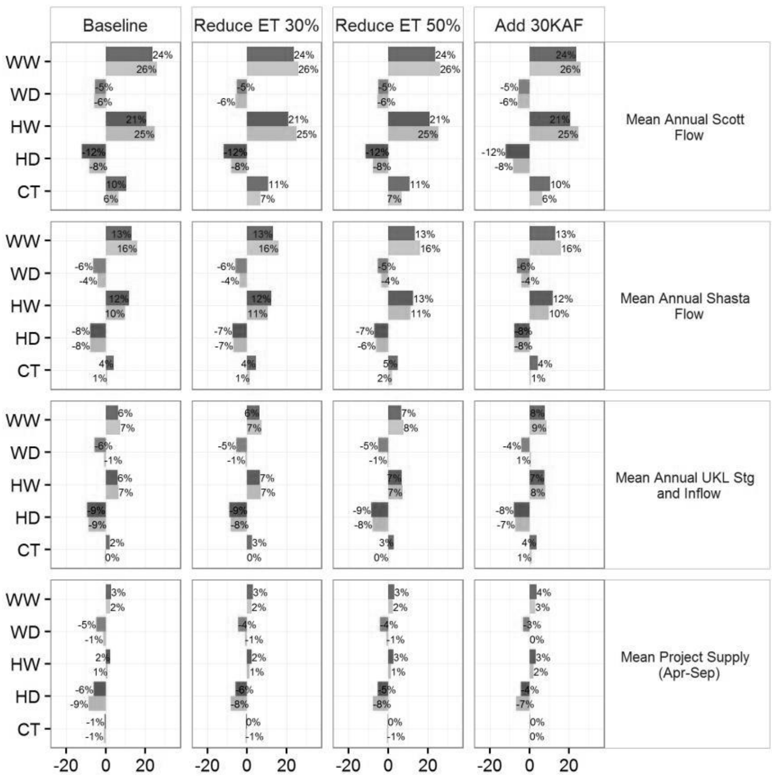
17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...



Projected changes in water supply measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-10 and for the 2070s in Figure 6-11. For the Scott and Shasta Rivers under the baseline scenario (climate change only), mean annual flow is projected to increase under wetter scenarios (WW and HW) and decrease under drier scenarios (WD and HD), with the CT scenario indicating a modest increase. For all scenarios, projected changes are greater for the 2070s time period than for the 2030s. For both rivers, reduction of agricultural demand (by 30 or 50 percent) does not appear to provide a substantial amount of additional flow volume, as indicated by no change or small change in the percent increase or decrease of mean annual flow. As expected, additional 30 KAF of inflow to Upper Klamath Lake does not impact mean annual flow in these rivers.

## Projected Klamath Project Supply

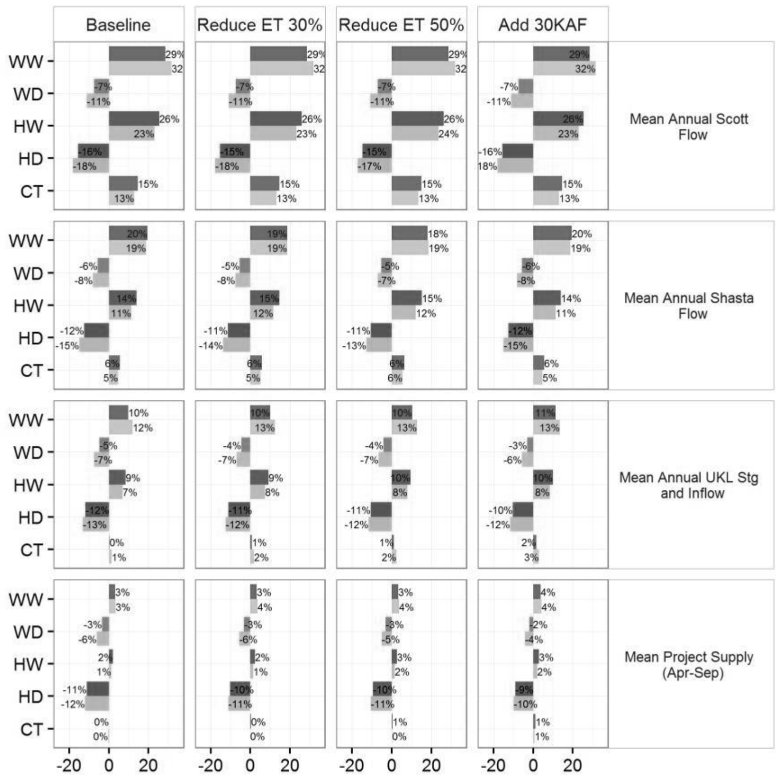
Neither reduction of agricultural demands nor additional 30 KAF inflow to Upper Klamath Lake have substantial impacts on mean Klamath Project water supply (April – September). However, the additional 30 KAF inflow does provides slightly greater additional supply than a reduction in agricultural demands.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-10. Projected change in water supply measures for the 2030s with strategies in place, expressed as percent change**

For the Upper Klamath Lake Supply measure, adaptation strategy concepts either result in no change or result in small increases in this value, thereby adding to increases in the measure for those climate change scenarios where there are increases (generally wetter scenarios), or decreasing the reduction for other scenarios (generally drier scenarios). Similarly, reduction of agricultural demands and additional inflow to Upper Klamath Lake do not have substantial impacts on mean April through September Klamath Project water supply. However, an additional 30 KAF provides greater additional supply than a reduction in agricultural demands, as indicated by greater increases in supply for the wetter scenarios and small decreases for the drier scenarios, compared with the historical simulation.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-11. Projected change in water supply measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.3 Analysis of Impacts – Hydroelectric Power

As discussed in Chapter 5, hydroelectric power measures considered in this study include mean number of spill days per year and mean annual spill volume at the major mainstem Klamath River power facilities (J.C. Boyle, COPCO 1, and Iron Gate), as well as mean annual hydropower generation summed over the four mainstem dams (those listed above plus COPCO 2). For the historical simulation period, mean annual days with spill at the three facilities are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate. The number of spill days and the mean annual spill volumes for J.C. Boyle and COPCO 1 are projected to increase for most scenarios for both future time horizons under the baseline (climate change with no strategies in place). At Iron Gate the projected spill volume generally increases, although by a lower percentage than at J.C. Boyle

and COPCO 1, and the projected mean number of spill days per year shows a small decrease.

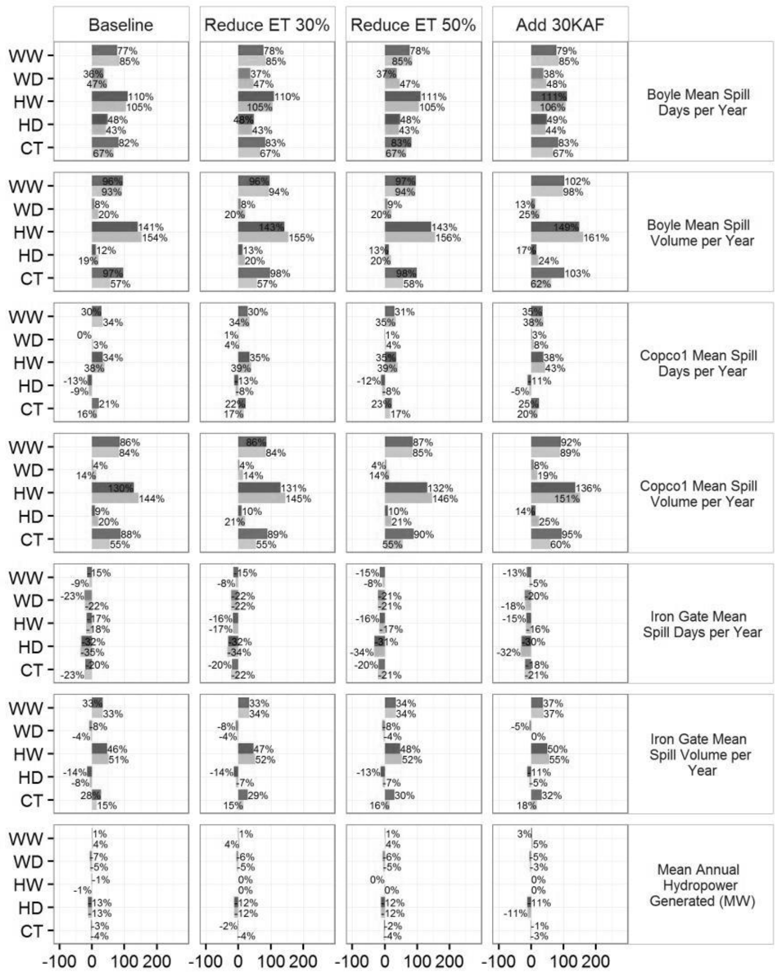
Projected changes in hydropower measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-12 and for the 2070s in Figure 6-13. The adaptation strategy concepts considered generally provide additional water to the mainstem Klamath River, thereby contributing to greater projected increases in mean number of spill days per year, mean annual spill volume, and mean annual hydropower production, more so for the 2070s than for the 2030s future time periods. Again, the addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes than does the decrease in agricultural demands. Projected changes in hydropower production are generally quite small compared with historical simulations, primarily because production under the historical simulation is on the order of 27,000 MW. In other words, hydropower production as a percentage does not change substantially due to the magnitude of hydropower production. Table 6-3 summarizes projected changes in mean annual hydropower production under the CT scenario for both future time periods. Implementation of the Add 30KAF strategy concept results in a 714 or 352 MW reduction in mean annual production for the 2030s, compared to 1,146 or 749 MW for the baseline (depending on consideration of CMIP3- or CMIP5-based projections). For the 2070s, the projected reduction is 468 or 1,209 MW, compared to 818 or 1,593 MW for the baseline.

## Projected Hydropower Production

The addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes in hydropower production than does the decrease in agricultural demands. Hydropower production as a percentage does not change substantially due to the magnitude of hydropower production (27,000 MW, according to historical simulations).

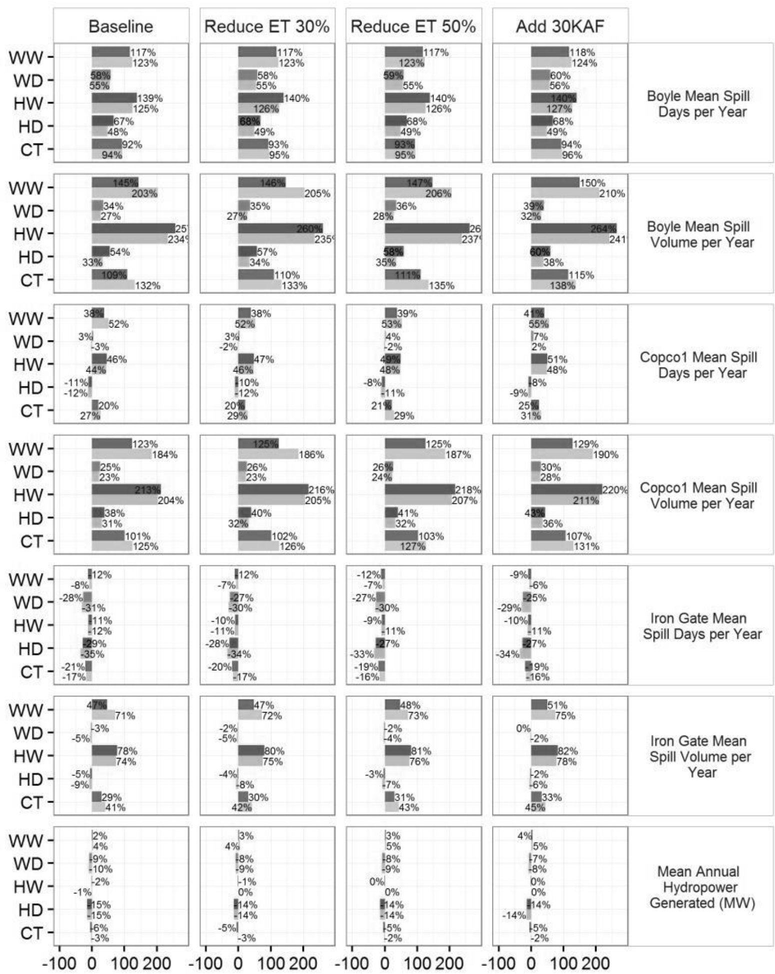
**Table 6-3. Summary of projected change in mean annual hydropower production for the Central Tendency scenario in units of MW**

| Central Tendency Scenario | CMIP | Baseline (MW) | Reduce ET 30% (MW) | Reduce ET 50% (MW) | Add 30KAF (MW) |
|---|---|---|---|---|---|
| Historical | | 26,741 | | | |
| 2030 | CMIP3 | -1,146 | -1,026 | -959 | -714 |
| | CMIP5 | -749 | -637 | -569 | -352 |
| 2070 | CMIP3 | -818 | -672 | -585 | -468 |
| | CMIP5 | -1,593 | -1,410 | -1,290 | -1,209 |




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-12. Projected change in hydroelectric power measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-13. Projected change in hydroelectric power measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.4 Analysis of Impacts – Recreation

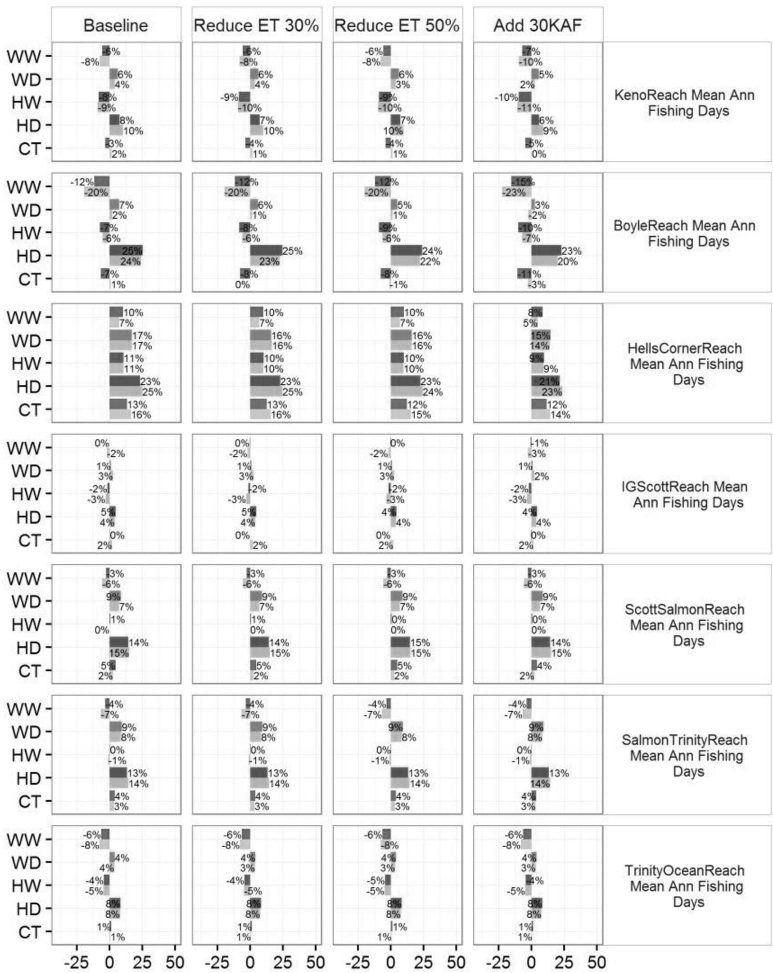
Recreation impacts are measured based on mean annual river boating days and mean annual fishing days in various reaches of the Klamath River. As discussed in Chapter 5, recommended flow ranges were summarized in the Environmental Impact Statement/Report for dam removal (Interior and CDFG, 2012). For the

historical simulations, mean annual number of fishing days are generally greater than mean annual number of river boating days. Projected changes in fishing measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-14 and for the 2070s in Figure 6-15, while projected changes in boating measures are summarized similarly in Figure 6-16 and Figure 6-17. For fishing under the baseline scenario (climate change with no strategies in place), the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios indicate decreases in the number of fishing days for both future time horizons. These results show that recommended flow ranges for fishing do not favor high flows. Because the adaptation strategy concepts generally result in greater mainstem river flows, their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The projected changes are small on a percentage basis (on the order of 1 to 2 percent). Implementation of the strategies does not counter the effects of climate change on fishing days.

## Recreation

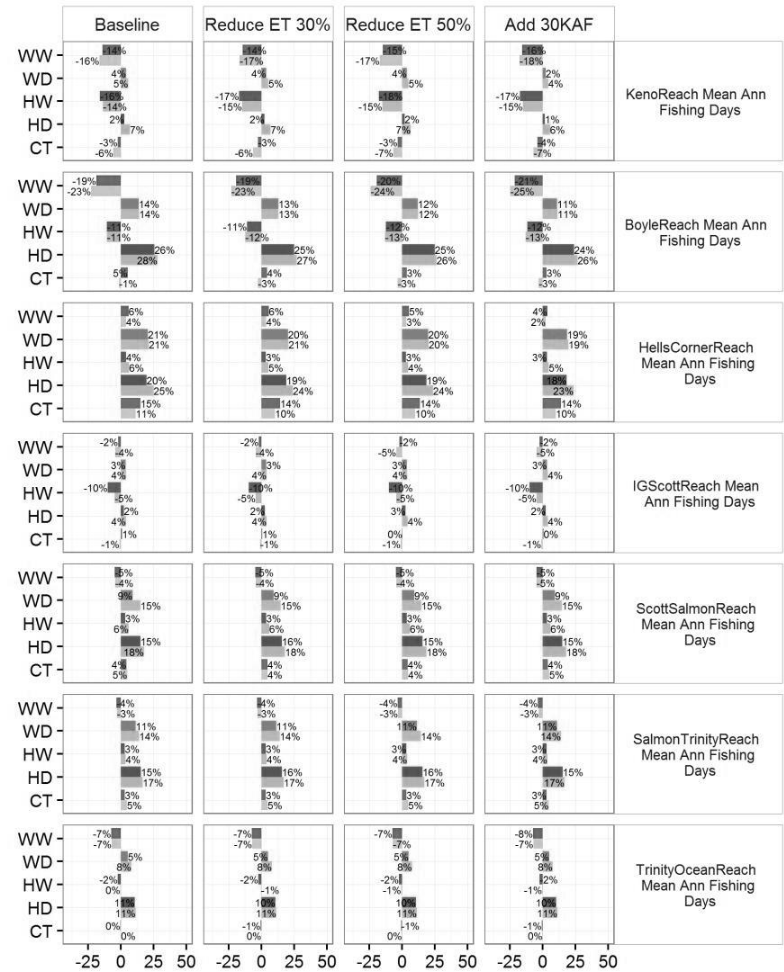
Adaptation strategy concepts generally result in greater mainstem river flows and their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The implementation of adaptation strategy results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. The implementation of adaptation strategy concepts (both agricultural demand reduction and additional inflow to Upper Klamath Lake) results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario. The strategies do not have a noticeable impact on boating recreation measures downstream of Iron Gate Dam. Upstream of Iron Gate, the strategies cause changes in the boating recreation measures by up to 2 percent for the 2030s and up to 4 percent for the 2070s, and more so for the Add 30KAF strategy scenario than for the agricultural demand reduction scenarios.



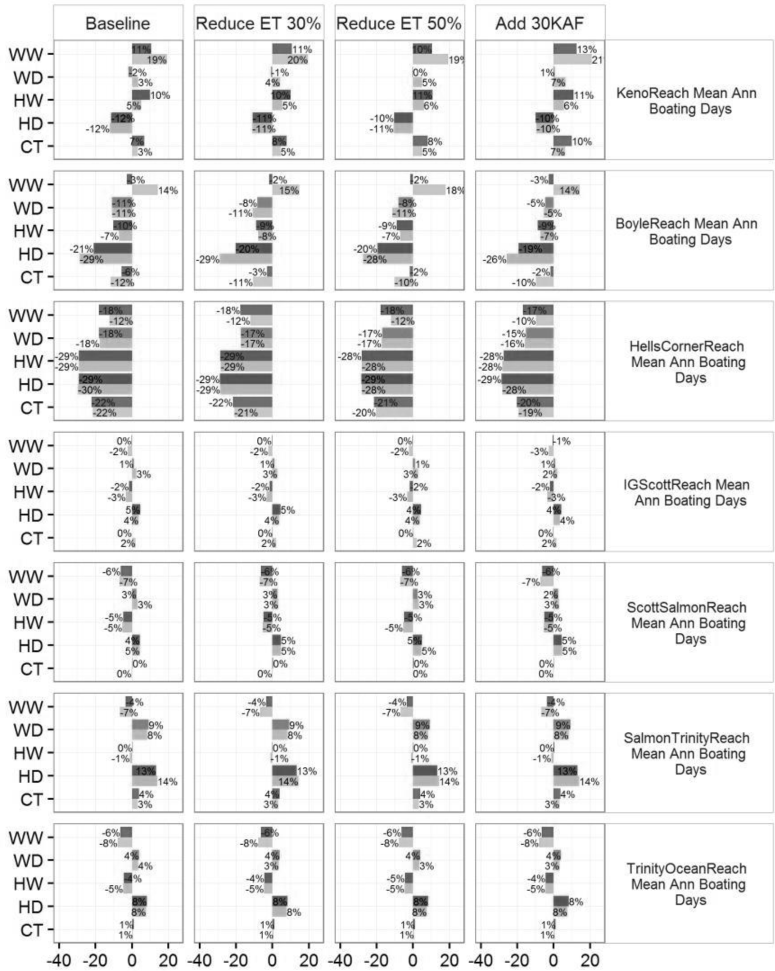

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-14. Projected change in fishing recreation measures for the 2030s with strategies in place, expressed as percent change**



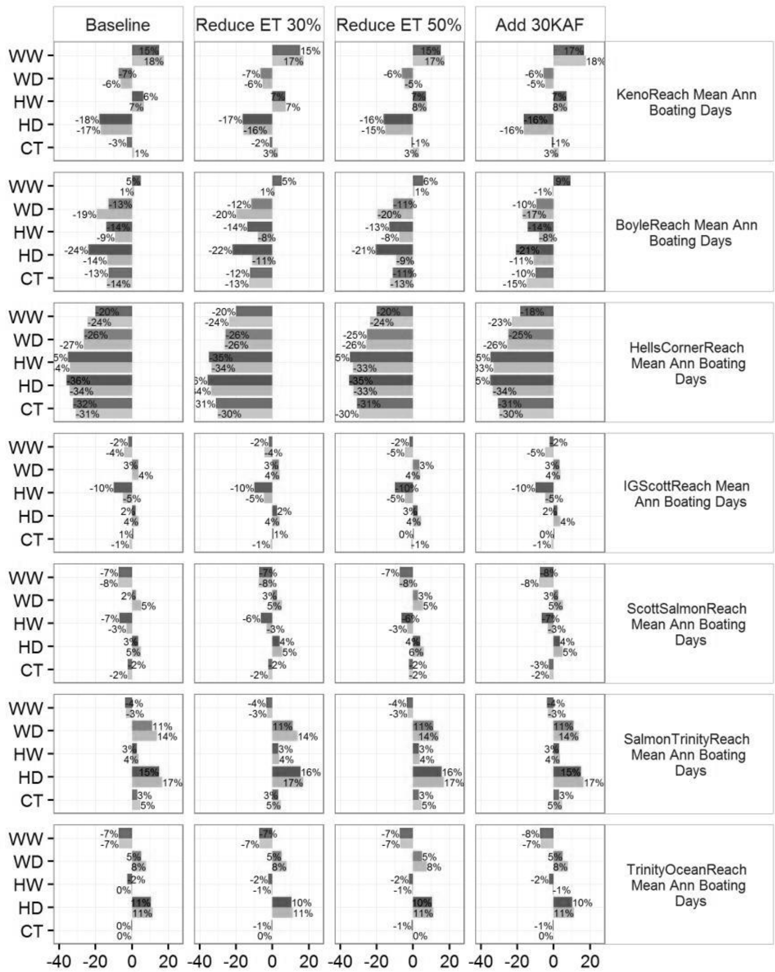

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-15. Projected change in fishing recreation measures for the 2070s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-16. Projected change in river boating recreation measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-17. Projected change in river boating recreation measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.5 Analysis of Impacts – Ecological Resources

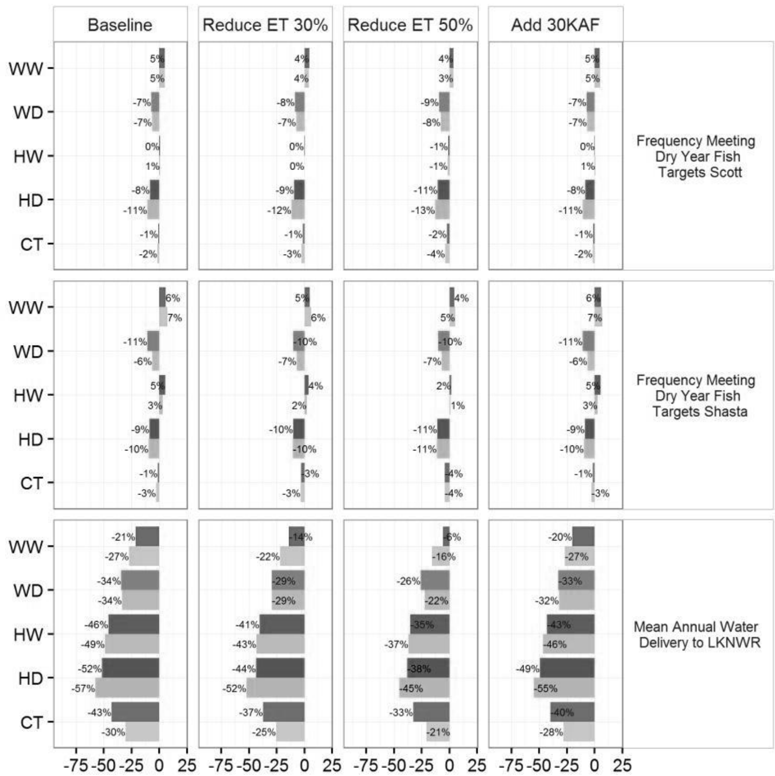
As discussed in Chapter 5, ecological resources measures considered in this study are related to needs for fish and wildlife habitat, including flow targets for SONCC ESU salmon and water supply to Lower Klamath National Wildlife Refuge (LKNWR). According to model simulations under historical hydrology, recommended flow targets that were developed specifically for the Shasta River

Basin were met 57 percent of days for the Shasta River and 71 percent of days for the Scott River (which has higher mean annual flow than the Shasta River).

Projected change in water supply measures under Baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-18 and for the 2070s in Figure 6-19. Projected changes under the baseline in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers indicate increases on a percentage basis for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and WD), with greater change projected for the 2070s time horizon compared with the 2030s. The baseline CT scenario indicates modest decreases in the frequency of meeting recommended flow targets. The Add 30KAF strategy does not impact flows in the Scott and Shasta Rivers, so the percent change under this strategy is identical to that of the baseline scenario. A reduction in agricultural demand in these basins appears to improve the ability to meet dry year fish targets for some scenarios, but not all.

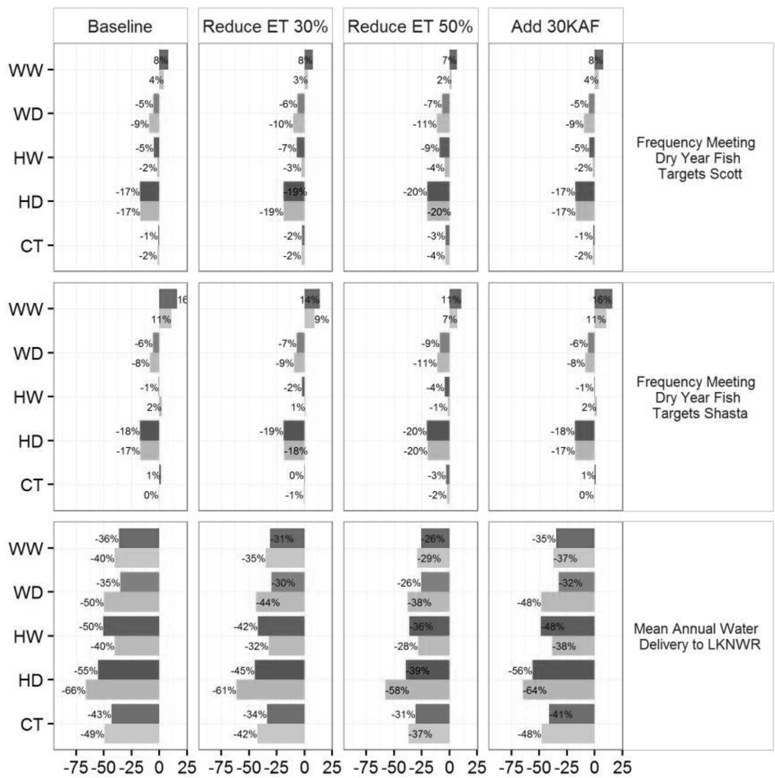
## Ecological Resources Impacts

The addition of 30 KAF of inflow to Upper Klamath Lake does not impact flows in the Scott and Shasta Rivers. Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. The additional Upper Klamath Lake inflow scenario also results in greater supply to the refuge, although to a lesser degree.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-18. Projected change in ecological resources measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-19. Projected change in ecological resources measures for the 2070s with strategies in place, expressed as percent change**

Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. For the 2030s, the projected reduction in water supply to LKNWR under the CT climate change scenario goes from a reduction of 30 or 43 percent (depending on the use of CMIP3 or CMIP5 scenarios) to a reduction of 21 or 33 percent if agricultural demands are cut in half. The Add 30KAF scenario also results in greater supply to the refuge, although to a lesser degree. For the 2070s, a 50 percent reduction in agricultural demands results in a change in the measure from 43 or 49 percent (under the baseline scenario) to 41 or 48 percent.

It may be noted that model results indicate a decrease in deliveries to LKNWR under all adaptation strategy concepts, albeit to a lesser extent than the baseline

scenario (climate change only). These results may in part be due to the fact that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Since Klamath Project supply is not projected to change substantially as a result of adaptation strategies, projected additional releases from Upper Klamath Lake may provide a greater benefit to the refuge.

### 6.4.6 Analysis of Impacts – Water Quality

As discussed in Chapter 5, water quality measures considered in this study are related to Klamath River temperature. The SONCC ESU salmon recovery plan (NMFS, 2012) provides a classification of river conditions based in part on the maximum weekly average temperature (MWAT). River temperatures were simulated using the RBM10 water temperature model developed by Perry et al. (2010). According to model simulations under historical hydrology, the river temperatures (as defined by the MWAT) for all simulated years were classified as "poor" under the salmon recovery plan. The "poor" classification threshold is 63.68 degrees F, or 17.6 degrees C. The measure considered by the basin study is the mean annual MWAT.

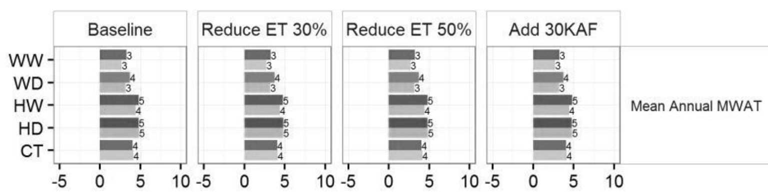
> **Water Quality Impacts**
>
> Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on water quality measures. Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow.

Projected changes in water quality measures under baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-20 and Figure 6-21 and for the 2070s in Figure 6-22 and Figure 6-23. It should be noted that additional adaptation strategy concepts were considered that affect river temperature. One additional strategy (labeled "Reduce Scott Shasta 4degC") focuses on reducing river temperature in the Scott and Shasta rivers by 4 degrees C (about 7 degrees F), in accordance with an existing emergency water management plan in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs.

Other additional strategies fall under the adaptation strategy concept of evaluating the sensitivity of river temperature to changes in tributary river temperature or streamflow. These strategies include adding 10 or 20 percent of flow to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River. These strategies are labeled as "Add Flow 10%" and "Add Flow 20%", respectively. They also include reducing input river temperatures in different locations represented in the RBM10 model. These strategies are labeled "Reduce Tribs 4degC" and "Reduce Dam outflow 4degC." "Reduce Tribs 4degC" includes reduction in temperature for all

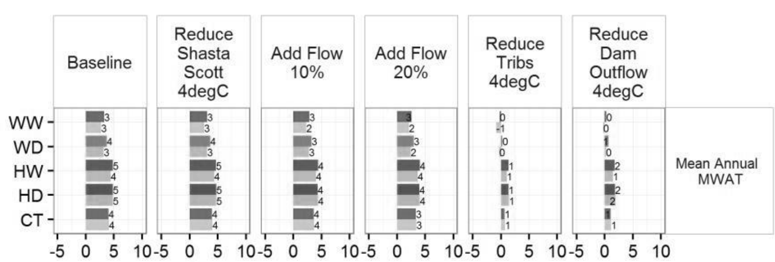
tributaries represented in the RBM10 model. “Reduce Dam Outflow 4degC” includes reducing outflow temperatures by 4 degrees C from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River.

Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on either water quality measure. The 2030s time period (summarized by Figure 6-20) shows no change, while the 2070s time period (summarized by Figure 6-22) shows no change based on reduction of agricultural demand by 30 percent and minimal change for the other two strategies. Figures 6-21 and 6-23 illustrate that Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow. Increasing tributary flows by 20 percent has a minimal impact on Klamath River temperatures, while reducing river temperature at specific locations (where possible) results in countering climate change effects substantially, although less so by the 2070s.



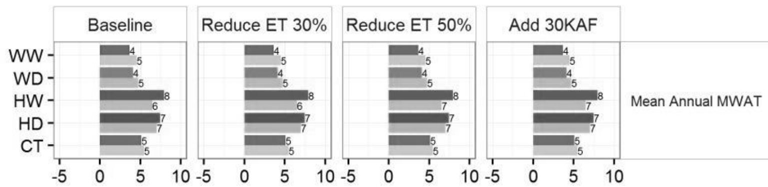

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-20. Projected change in water quality measures for the 2030s with strategies in place, expressed as degrees C**



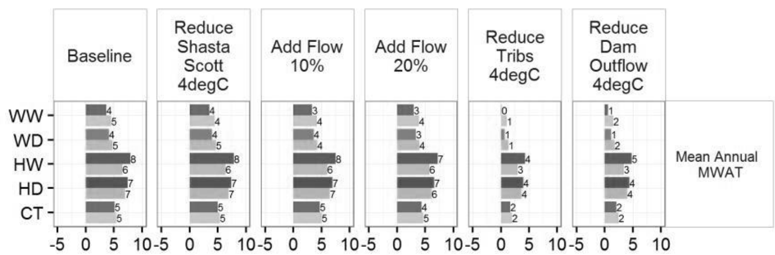

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-21. Projected change in water quality measures for the 2030s with additional strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-22. Projected change in water quality measures for the 2070s with strategies in place, expressed as degrees C**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-23. Projected change in water quality measures for the 2070s with additional strategies in place, expressed as percent change**

### 6.4.7 Analysis of Impacts – Flood Control

As discussed in Chapter 5, flood control measures include (1) the frequency (mean number of days per year) of flood control releases from Upper Klamath Lake, (2) the mean annual flood control release volume (based on water year) from Upper Klamath Lake, and (3) the date of seasonal peak flow at three locations (J.C. Boyle Reservoir, COPCO 1 Reservoir, and Iron Gate Reservoir). Measures are computed using results from the Klamath Basin RiverWare model. Again, flood control release from Upper Klamath Lake is defined in the 2012 Proposed Action for Klamath Project Operations (Reclamation, 2012d), which is quantified as the release beyond that made to meet Klamath Project deliveries and to meet instream flow needs. Projected change in Upper Klamath Lake flood control measures under baseline and adaptation strategy concept scenarios are summarized in Figure 6-24 (2030s) and Figure 6-25 (2070s). Table 6-4 quantifies the difference between projected flood control release volume in units of KAF and the historical baseline, which addresses the question of how much additional surface water may be available for future storage under the “Additional Surface Water Storage Capacity” strategy concept.

The frequency of Upper Klamath Lake flood control release under the historical simulation is about 44 percent of days, while the corresponding mean annual flood control release volume is approximately 224 KAF. As previously discussed, flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. Even under historical hydrology, 44 percent of days may seem high for the percent of days of flood control release from Upper Klamath Lake. The characterization of flood control release is consistent between the RiverWare model and the KBPM. However, greater simulated flows in the Lost River system, compared with KBPM, may result in smaller demand from Upper Klamath Lake for Klamath Project supply, and therefore greater flood control release.

## Flood Control Impacts

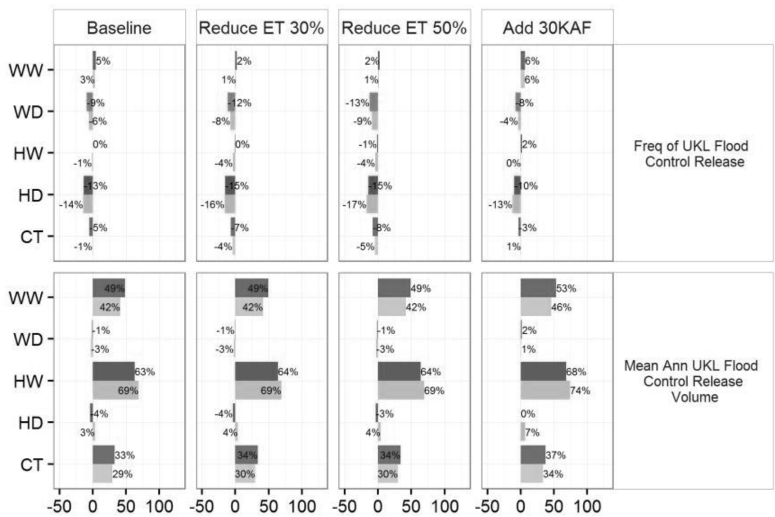
The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume. Model results indicate substantial surface water available for storage in a future climate, due to a combination of decreased snowpack and increased precipitation on an annual basis. Adaptation strategy concepts have small effects on the mean date of seasonal peak flow, indicating a difference of 2 days or less.

Projected changes indicate minimal change for the wetter scenarios (WW and HW) and a decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. At the same time, for all scenarios there is a projected increase in the mean annual flood control volume, suggesting that more water is being released in the future even though the occurrence of release may be decreasing.

Under adaptation strategy concepts in which there is a reduction in agricultural demands, additional water causes greater increases in flood control release for the wetter scenarios, and smaller decreases for the drier scenarios. The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume.

Projected changes in the date of seasonal peak flow are less substantial at J.C. Boyle Reservoir than at COPCO 1 and Iron Gate dams (refer to Table 6-5 through Table 6-7). The baseline scenario dates of seasonal peak flow are April 9 at J.C. Boyle, April 17 at COPCO 1, and April 15 at Iron Gate. Projected baseline scenario climate change effects at J.C. Boyle range from 1 to 4 days later for the 2030s to 4 days earlier to 3 days later for the 2070s, depending on the climate scenario. For COPCO 1 and Iron Gate, projected changes range from 1 day later to 9 days earlier for the 2030s and about 2 days to 2 weeks earlier for the 2070s.

Considering the adaptation strategy concepts and their effect on mean date of seasonal peak flow, both reduction of agricultural demand and addition of 30 KAF of inflow to Upper Klamath Lake have small effects, generally resulting in peak flow dates that are different by 2 days or less from the baseline. This is true at all three dam locations evaluated.

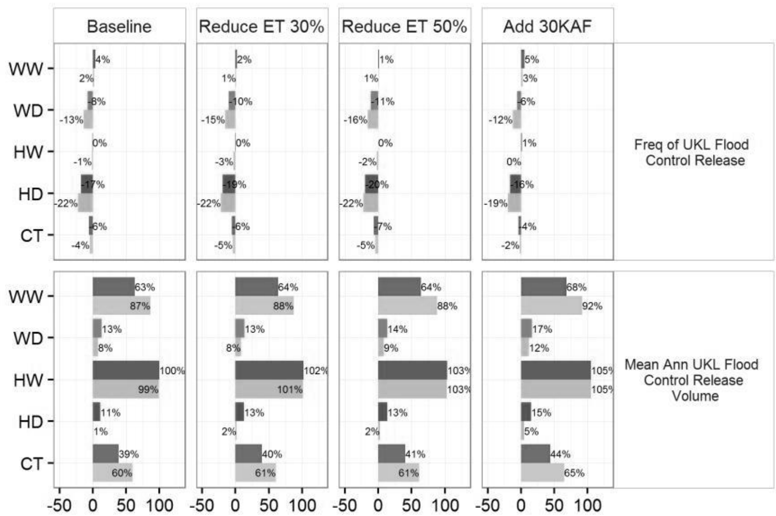



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-24. Projected change in flood control measures for the 2030s with strategies in place, expressed as percent change**

17-01174_012000;17-01174_012000;17-01174_012001;17-01174_012002;17-01174_012003;17-01174_012004;1...






Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-25. Projected change in flood control measures for the 2070s with strategies in place, expressed as percent change**

Because the mean annual Upper Klamath Lake flood control release volume is a system performance measure and is also the variable used to quantify the adaptation strategy concept pertaining to additional storage volume, we summarize the projected flood control release volume for all climate change scenarios at both future time horizons. According to model simulations and the means of quantifying flood control release (i.e., that release volume beyond Klamath Project deliveries and environmental flow releases), there may be substantial additional surface water available for storage under future climate conditions. This volume may be due to projected increases in precipitation and/or the reduction in snowpack storage as temperatures are projected to warm.

**Table 6-4. Projected change in mean annual Upper Klamath Lake flood control release volume, computed as difference (in units of KAF) between scenario and historical baseline**

| Scenario | Period | BCSD Projection | Baseline (KAF) | Reduce ET 30% (KAF) | Reduce ET 50% (KAF) | Add 30KAF (KAF) |
|---|---|---|---|---|---|---|
| Historical | Historical | - | 224 | | | |
| Warm Dry | 2030 | CMIP-3 | -6 | -5 | -5 | 2 |
| Warm Dry | 2030 | CMIP-5 | -3 | -2 | -2 | 5 |
| Warm Wet | 2030 | CMIP-3 | 94 | 94 | 94 | 103 |
| Warm Wet | 2030 | CMIP-5 | 110 | 111 | 111 | 120 |
| Hot Dry | 2030 | CMIP-3 | 8 | 9 | 9 | 16 |
| Hot Dry | 2030 | CMIP-5 | -9 | -8 | -7 | 1 |
| Hot Wet | 2030 | CMIP-3 | 155 | 156 | 156 | 167 |
| Hot Wet | 2030 | CMIP-5 | 142 | 144 | 145 | 153 |
| Central Tendency | 2030 | CMIP-3 | 67 | 67 | 68 | 76 |
| Central Tendency | 2030 | CMIP-5 | 75 | 76 | 77 | 84 |
| Warm Dry | 2070 | CMIP-3 | 19 | 19 | 20 | 27 |
| Warm Dry | 2070 | CMIP-5 | 30 | 31 | 31 | 38 |
| Warm Wet | 2070 | CMIP-3 | 195 | 197 | 198 | 207 |
| Warm Wet | 2070 | CMIP-5 | 143 | 144 | 144 | 153 |
| Hot Dry | 2070 | CMIP-3 | 2 | 5 | 6 | 12 |
| Hot Dry | 2070 | CMIP-5 | 25 | 29 | 31 | 35 |
| Hot Wet | 2070 | CMIP-3 | 224 | 228 | 231 | 236 |
| Hot Wet | 2070 | CMIP-5 | 224 | 230 | 232 | 236 |
| Central Tendency | 2070 | CMIP-3 | 135 | 137 | 138 | 147 |
| Central Tendency | 2070 | CMIP-5 | 87 | 89 | 92 | 99 |

**Table 6-5. Projected change in date of seasonal peak flow at J.C. Boyle Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle |
| Historical | Historical | - | April 9 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 4 | 4 | 4 | 4 |
| Warm Dry | 2030 | CMIP-5 | 4 | 4 | 4 | 3 |
| Warm Wet | 2030 | CMIP-3 | 2 | 2 | 2 | 2 |
| Warm Wet | 2030 | CMIP-5 | 2 | 2 | 2 | 2 |
| Hot Dry | 2030 | CMIP-3 | 4 | 4 | 4 | 3 |
| Hot Dry | 2030 | CMIP-5 | 4 | 4 | 4 | 3 |
| Hot Wet | 2030 | CMIP-3 | 1 | 1 | 1 | 1 |
| Hot Wet | 2030 | CMIP-5 | 2 | 2 | 2 | 2 |
| Central Tendency | 2030 | CMIP-3 | 3 | 3 | 3 | 3 |
| Central Tendency | 2030 | CMIP-5 | 2 | 2 | 2 | 1 |
| Warm Dry | 2070 | CMIP-3 | 2 | 4 | 3 | 2 |
| Warm Dry | 2070 | CMIP-5 | 3 | 3 | 3 | 3 |
| Warm Wet | 2070 | CMIP-3 | 2 | 2 | 2 | 1 |
| Warm Wet | 2070 | CMIP-5 | 2 | 2 | 2 | 2 |
| Hot Dry | 2070 | CMIP-3 | 3 | 4 | 3 | 2 |
| Hot Dry | 2070 | CMIP-5 | 1 | 2 | 2 | 1 |
| Hot Wet | 2070 | CMIP-3 | -2 | 1 | -2 | -3 |
| Hot Wet | 2070 | CMIP-5 | -4 | -3 | -3 | -4 |
| Central Tendency | 2070 | CMIP-3 | 0 | 3 | 0 | 0 |
| Central Tendency | 2070 | CMIP-5 | 2 | 2 | 2 | 2 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

**Table 6-6. Projected change in date of seasonal peak flow at COPCO 1 Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 |
| Historical | Historical | - | April 17 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 1 | 1 | 1 | 1 |
| Warm Dry | 2030 | CMIP-5 | 0 | 0 | 0 | 0 |
| Warm Wet | 2030 | CMIP-3 | -4 | -4 | -4 | -5 |
| Warm Wet | 2030 | CMIP-5 | -5 | -5 | -5 | -5 |
| Hot Dry | 2030 | CMIP-3 | -4 | -3 | -3 | -4 |
| Hot Dry | 2030 | CMIP-5 | -3 | -3 | -3 | -3 |
| Hot Wet | 2030 | CMIP-3 | -9 | -9 | -9 | -9 |
| Hot Wet | 2030 | CMIP-5 | -8 | -8 | -8 | -8 |
| Central Tendency | 2030 | CMIP-3 | -3 | -4 | -3 | -4 |
| Central Tendency | 2030 | CMIP-5 | -6 | -6 | -6 | -6 |
| Warm Dry | 2070 | CMIP-3 | -5 | -5 | -4 | -5 |
| Warm Dry | 2070 | CMIP-5 | -2 | -2 | -2 | -2 |
| Warm Wet | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Warm Wet | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-3 | -8 | -7 | -7 | -8 |
| Hot Dry | 2070 | CMIP-5 | -8 | -8 | -8 | -8 |
| Hot Wet | 2070 | CMIP-3 | -15 | -15 | -14 | -15 |
| Hot Wet | 2070 | CMIP-5 | -17 | -17 | -17 | -17 |
| Central Tendency | 2070 | CMIP-3 | -10 | -10 | -10 | -11 |
| Central Tendency | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

**Table 6-7. Projected change in date of seasonal peak flow at Iron Gate Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate |
| Historical | Historical | - | April 15 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 1 | 1 | 1 | 0 |
| Warm Dry | 2030 | CMIP-5 | 0 | 0 | 0 | 0 |
| Warm Wet | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Warm Wet | 2030 | CMIP-5 | -5 | -5 | -5 | -5 |
| Hot Dry | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Hot Dry | 2030 | CMIP-5 | -3 | -3 | -3 | -3 |
| Hot Wet | 2030 | CMIP-3 | -9 | -9 | -9 | -9 |
| Hot Wet | 2030 | CMIP-5 | -8 | -8 | -8 | -8 |
| Central Tendency | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Central Tendency | 2030 | CMIP-5 | -6 | -5 | -5 | -6 |
| Warm Dry | 2070 | CMIP-3 | -5 | -5 | -5 | -5 |
| Warm Dry | 2070 | CMIP-5 | -2 | -2 | -2 | -2 |
| Warm Wet | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Warm Wet | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-5 | -8 | -8 | -7 | -8 |
| Hot Wet | 2070 | CMIP-3 | -14 | -14 | -13 | -14 |
| Hot Wet | 2070 | CMIP-5 | -16 | -16 | -15 | -16 |
| Central Tendency | 2070 | CMIP-3 | -10 | -10 | -10 | -10 |
| Central Tendency | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

## 6.5 Key Findings and Next Steps

Klamath River water users and stakeholders have long have long called for a comprehensive and integrated approach to water management to balance the needs of all water users. The Basin Study Report evaluates current and projected future water supply and demand assessments to refine existing projections of climate change's effect on the Klamath River Basin, and provide stakeholders in the region the opportunity to identify and evaluate potential adaptation strategies which may reduce identified imbalances. These adaptation strategies provide water users, stakeholders, and Reclamation with understanding of the degree to which actions including those to increase supply, decrease demand, and modify operations could reduce supply and demand imbalances that are projected to increase as a result of climate change. The Basin Study builds on earlier work and is the next significant step in developing a comprehensive knowledge base

and suite of tools and options that could address the risks posed by Klamath River Basin water supply-demand imbalances.

Results from model simulations with and without adaptation strategy concepts in place indicate that the strategies have modest abilities to reduce climate change impacts. Considered strategies include agricultural water conservation, additional inflow to Upper Klamath Lake, quantification of potential surface water storage, and evaluation of changes in flow and tributary temperature on Klamath River temperature at Klamath, California.

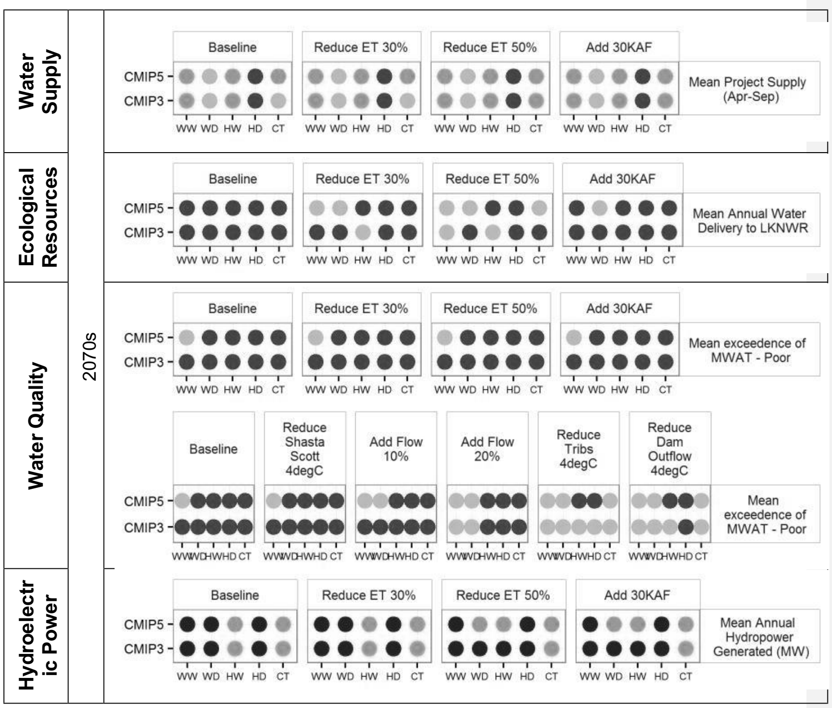
The addition of inflow to Upper Klamath Lake appears to result in the greatest change in computed basin-wide response variables and selected performance measures. With respect to sensitivities of river temperature, the reduction in tributary temperature has a greater impact than does change in flow. Also, according to model simulations, substantial surface water may be available for storage in the future due to reduction in snowpack storage and projected changes in precipitation timing and volume. The location for quantification of additional storage is at Upper Klamath Lake; however, this study does not explore locations for future surface water storage.

Figure 6-26 summarizes projected changes in four select system performance measures for the 2070s future time period, compared with the historical simulation. Projected changes are computed using CMIP3- and CMIP5-based projections, and for each of the five climate change scenarios. The baseline scenario represents climate change only, without adaptation strategy concepts in place. The other scenarios represent changes with adaptation strategy concepts. For this figure, projected changes on a percentage basis were divided into four bins: two bins for positive change and two bins for negative change. Darker circles represent the bin with greater change. Green circles indicate an improvement in the selected measure, while red circles indicate a worsening of the measure. The results summarized in the figure allow for a high level understanding of the direction of change, and highlight which strategies provide the greatest change compared with the baseline scenario.

In Figure 6-26, with respect to mean April–September Klamath Project supply, neither reduction in agricultural demand nor additional Upper Klamath Lake inflow of 30 KAF cause a substantial change compared with the baseline scenario. For mean annual water supply to LKNWR, reduction in agricultural demands results in a meaningful improvement, compared with the baseline scenario. For mean exceedance of the “poor” water quality classification (through calculation of the MWAT), reduction in tributary water temperatures has a greater influence on resulting river temperatures than changes in streamflow. It is likely not realistic to expect a reduction in temperatures in unmanaged tributaries, but changes in managed flows (i.e., Link River, Shasta River, Scott River, Trinity River) still have a meaningful impact, compared with the baseline scenario. For mean annual hydropower generation, it is apparent that climate change, and adaptation strategy concepts, result in greater hydropower production. Reduction

of agricultural demands by 50 percent and additional Upper Klamath Lake inflow of 30 KAF result in noticeable change from the baseline, while a less substantial reduction in agricultural demands (30 percent) does not provide substantial additional benefit.

Overall, climate change adversely affects mean annual deliveries to LKNWR and river temperatures; it may adversely affect or may be favorable to mean Klamath Project Supply (April–September) depending on the climate change scenario, and is likely to be favorable to mean annual hydropower production. Adaptation strategy concepts evaluated in the Basin Study do not substantially counter the effects of climate change. However, in general the addition of 30 KAF inflow to Upper Klamath Lake appears to have a greater benefit to the system reliability than does reduction in agricultural demands, based on model simulations.




Notes: Green circles indicate an improvement in the measure for the future, while red circles indicate a worsening in the measure for the future. Darker circles indicate greater change than lighter circles.

**Figure 6-26. Summary of projected changes in select measures for the 2070s, with and without strategies in place**

### 6.5.1 Refinement of Adaptation Strategies and Next Steps

The Basin Study Report indicates that implementation of projects to improve water supply, decrease demand, and modify operations can provide some improvement in the reliability and sustainability of the Klamath River system to help meet current and future water demands. The adaptation strategies evaluated in this Basin Study would all need to be further studied to refine the understanding of these potential benefits and develop plans for their implementation. Similar to this Basin Study, the agencies and stakeholders that would need to be involved in that refinement process would need to include all those potentially affected by their implementation.

The Klamath River Basin Study relied on projected future conditions that were developed utilizing existing model frameworks and inputs. Identified adaptation strategies evaluated by the Basin Study are general (i.e., not specific proposed projects) by design and are intended to identify sensitivities of the Klamath Basin to various types of potential actions. Moving forward, a number of tasks have been identified to further enhance our understanding of climate change impacts on the Klamath River Basin.

- Refinement of ecosystem demands and vulnerabilities – Additional analysis of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems that result from changes in the climate, and the ability to accommodate these demands with existing supplies would further support and refine the findings in this study. Additionally, incorporation of developing river temperature modeling for the Trinity River by the U.S. Geological Survey could enhance our understanding of climate change impacts and implemented adaptation strategies on river temperatures.

- Coupled groundwater/surface water model development – Expansion of existing groundwater models for the Scott and Shasta rivers to cover broader portions of the basin would further support the analysis completed in this Basin Study.

- Reservoir Operations Refinement – Current funding by the Bureau of Reclamation Office of Policy for a Klamath River Basin reservoir operations pilot study on Upper Klamath Lake will enhance the ability to quantify Upper Klamath Lake inflows and provide for an improved understanding of Upper Klamath Lake operations.

- Effects of future policy changes – Evolving policy conditions are anticipated in the Klamath River Basin relating to future ESA consultations and potential removal of the four mainstem Klamath River dams. Continued analysis of future policies using the Basin Study modeling framework will allow for comparisons to be made, and for greater understanding of potential climate change impacts.

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17-01174_012330;17-01174_012330

RECLAMATION

*Managing Water in the West*

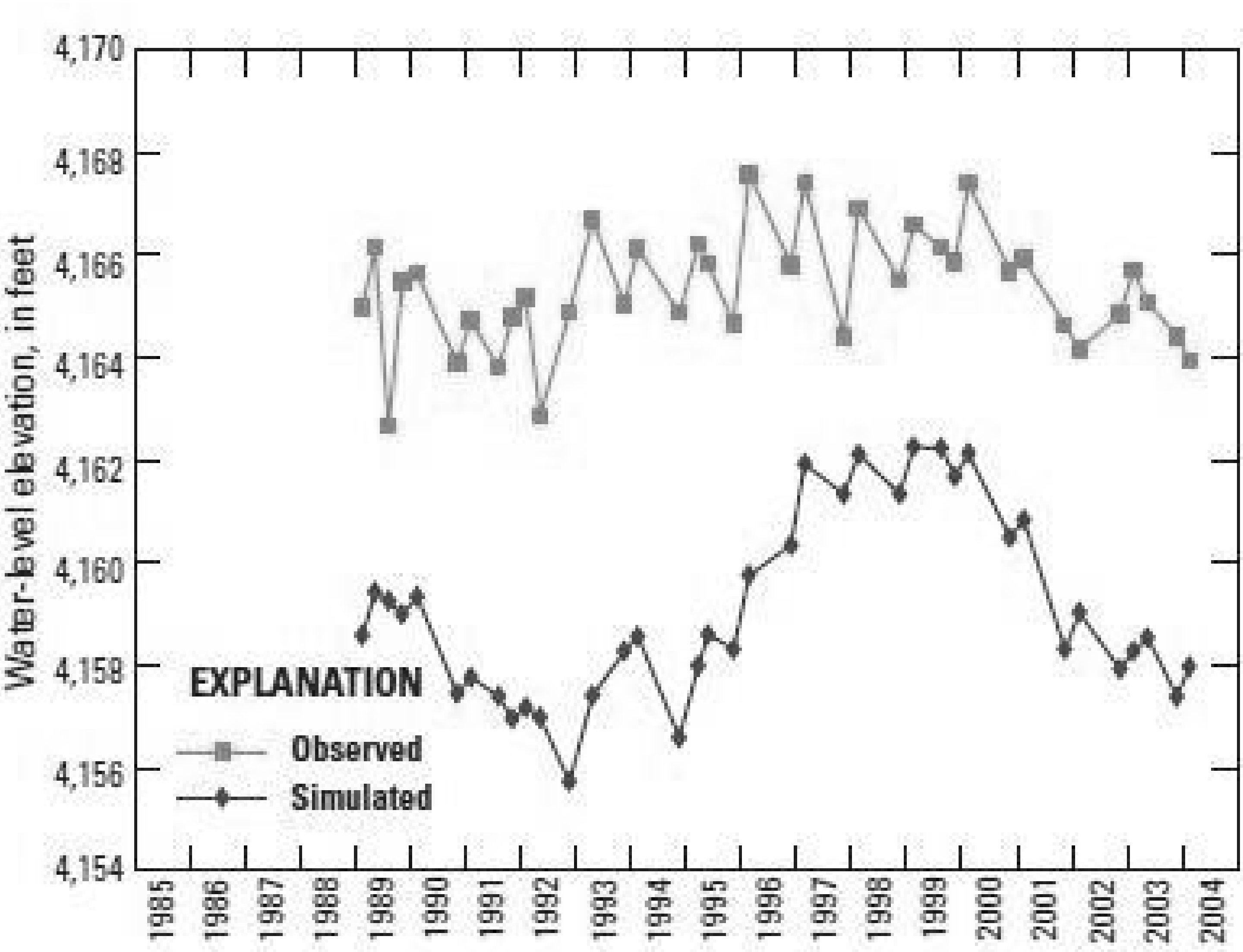


**Figure 18.** Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

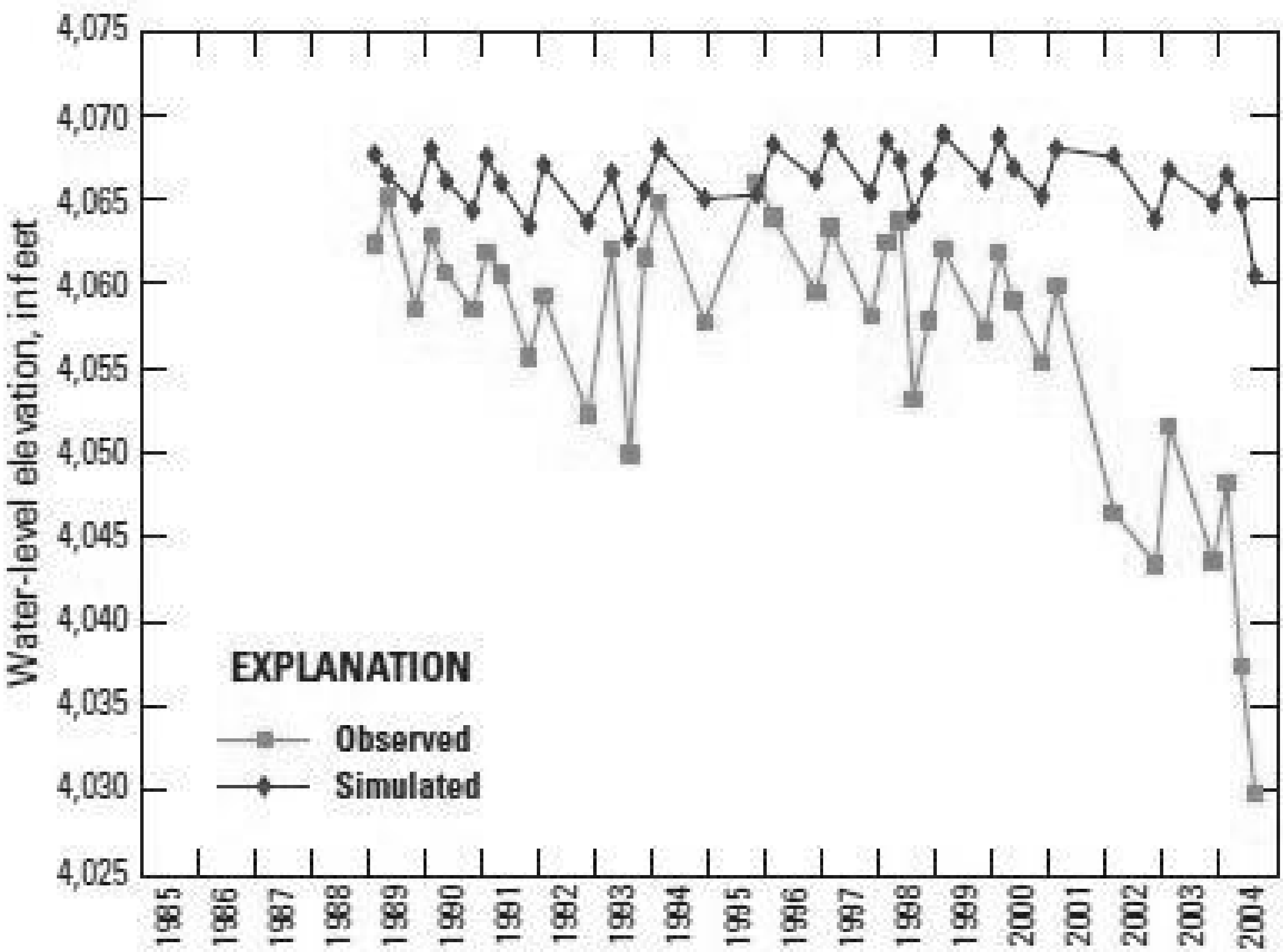


**Figure 36.** Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

**To:** Erath, Amanda[aerath@usbr.gov]
**Cc:** David Raff[draff@usbr.gov]; Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-19T08:36:25-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-19T08:36:56-04:00

Thanks. I'll look this over and get back to you early next week.
Regards,
Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

> Hello Goks,
> Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter). [redacted] (b)(5) (b)(5) lease let me know if you have any questions.
>
> [redacted] (b)(5)
>
> ***Amanda Erath***
> *Program Analyst*
> Policy and Administration
> Denver Federal Center
> Building 67 (84-51000)
> P.O. Box 25007
> Denver, CO 80225-0007
>
> *Office*: (303) 445-2766
> *Email*: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

---

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted] (b)(5)

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted] (b)(5)

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

**To:** James Cason[james_cason@ios.doi.gov]
**Cc:** Indur Goklany[indur_goklany@ios.doi.gov]
**From:** Nichols, Ryan
**Sent:** 2017-05-19T11:40:33-04:00
**Importance:** Normal
**Subject:** Fwd: Niobrara Basin Study Final Report
**Received:** 2017-05-19T11:40:53-04:00
Niobrara Basin Study Summary Report.docx
NiobraraBasinStudy_AppA.docx

Jim,

I'm writing to inform you that a second basin study has been completed by the Bureau of Reclamation, this time on the Niobrara Basin. The study relies on the same climate science modelling as the Klamath River Basin Study.

Attached is the Summary Report for the Niobrara Basin Study. If you'd like I could print a hard copy for your review and bring it to your office.

Ryan Nichols
Special Assistant to the Secretary
Department of the Interior

RECLAMATION
*Managing Water in the West*

# Niobrara River Basin Study Summary Report

U.S. Department of the Interior
Bureau of Reclamation

Technical Service Center
Denver, Colorado

Nebraska-Kansas Office
McCook, Nebraska

Nebraska
Department of Natural Resources
Lincoln, Nebraska

December 2016

# Mission Statements

## Department of the Interior

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

## Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

## Nebraska Department of Natural Resources

The Nebraska Department of Natural Resources is dedicated to the sustainable use and proper management of the State's natural resources.

Cover photo: Autumn colors along the Niobrara River, as seen from the Cornell Bridge in the Fort Niobrara National Wildlife Refuge. Photo by National Park Service.

# Niobrara River Basin Study Summary Report

**U.S. Department of the Interior**
**Bureau of Reclamation**

Nebraska

Technical Service Center
Denver, Colorado

Nebraska-Kansas Office
McCook, Nebraska

Department of Natural Resources
Lincoln, Nebraska

**December 2016**

# Disclaimer

The Niobrara River Basin Study was funded jointly by the Bureau of Reclamation (Reclamation) and the Nebraska Department of Natural Resources and is a collaborative product of the study participants as identified in section I-C of this report. The purpose of the study is to assess current and future water supply and demand in the Niobrara Basin and to identify a range of potential strategies to address any projected imbalances. The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the Nebraska Department of Natural Resources. The study does not propose or address the feasibility of any specific project, program or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

# Executive Summary

Spanning portions of eastern Wyoming, southern South Dakota, and northern Nebraska, the Niobrara River Basin (Basin) links land and water to support a diverse natural environment, rich with life. The vast east-west riparian corridor is 535 river miles in length and drains 12,600 square miles. As the longest river in Nebraska, the Niobrara River reaches across the 100$^{th}$ Meridian to connect a semiarid western landscape with a more humid, mid-western prairie. This is a Basin where ecosystems converge resulting in a unique arrangement of forest cover and mixed-grass prairie. A 76-mile stretch of the Niobrara River is lined with fossil-filled sandstone cliffs that host over 200 waterfalls and is protected under the U.S. National Park Service's National Scenic River system (1991).

While beautiful and biologically diverse, the Niobrara River also gives life to farming communities and provides great economic value. Hydrologically linked with the underlying High Plains Aquifer system, the Niobrara River irrigates approximately 600,000 acres, supplies drinking water to nearly 20,000 people, and generates recreational revenues for local economies. Competition for limited water resources in the Basin is intense. As water management practices respond to a changing climate and competing demands, there is a need for a better understanding of what effect water imbalances may have on the vitality of the Basin area and how they can be addressed.

Like many river basins in the western United States (U.S.), the Basin represents a variety of water management challenges. Competition for limited water resources gives rise to imbalances too often revealed in the form of shortages for water right holders. Groundwater irrigation development is prevalent and a strong hydrologic connection between groundwater and surface water further complicates surface water supplies in the Basin. This interaction is recognized in the Upper Niobrara Basin (Upper Basin) where the Mirage Flats Irrigation District (MFID) is currently receiving only a fraction of the surface water supply that was once delivered prior to widespread development of groundwater irrigation. Hydrologic records give no indication that greater surface water supplies for irrigation are to be expected in the future. Working together, a further understanding of water resources in the Basin will help stakeholders respond to future challenges and opportunities to better secure limited water supplies.

## Basin Study Value

### *Fostering Collaboration*

This Niobrara River Basin Study (Basin Study) engages a broad spectrum of stakeholders to explore complex water management issues in a collaborative

setting with the Bureau of Reclamation (Reclamation) and the Nebraska Department of Natural Resources (DNR). While this Basin Study does not propose implementation of a specific project, program, or plan, it does provide a catalyst for collaboration among stakeholders including Reclamation, Nebraska DNR, National Park Service, United States Fish and Wildlife Service (USFWS), Nebraska Game and Parks Commission, the Upper Niobrara-White River (UNW) Natural Resources District (NRD), the Upper Loup NRD, the Upper Elkhorn NRD, the Middle Niobrara NRD, the Lower Niobrara NRD, MFID, Ainsworth Irrigation District (AID), and Nebraska Public Power District.

Specifically, this Basin Study provided an opportunity for Reclamation and Nebraska DNR to attend a series of meetings with stakeholders to discuss resource challenges. These meetings offered a venue for gathering input, addressing concerns, and exploring shared responsibilities. Discussions ranged from important on-the-ground field experiences to high-level technical perspectives. A number of varied interests were represented at stakeholder meetings, including irrigation, drinking water supply, fish and wildlife, hydropower, and recreation.

### *Expanding Science*

As stakeholder input is gathered, this Basin Study also explores ways to improve water management and system reliability by employing technical resources that can expand the reach of science within the Basin. This approach is an important initial step toward a more comprehensive long-range plan for the Basin. In the long-term, this Basin Study will help inform the Nebraska DNR and Basin stakeholders responsible for the ongoing development of a Basin-wide Management Plan that focuses on achieving sustainable balance between water users and water suppliers. As this Basin Study concludes, it is anticipated that the Basin-wide Management Plan will continue to be developed as part of a Basin-wide planning process that continues to build upon on the science and analysis presented in this Basin Study.

This Basin Study also provides foundational information for development and implementation of Integrated Management Plans designed by the Nebraska DNR and local NRDs. Integrated Management Plans help achieve and sustain a balance between water uses and water supplies for the long term. The core components of Integrated Management Plans rely on utilization of sound science and an accurate understanding of water principles within the Basin. This Basin Study offers an additional resource that can help inform decision makers as they identify appropriate goals and continue monitoring overall effectiveness of Integrated Management Plans.

### *Enhancing Modeling Capacity*

This Basin Study increases overall modeling capabilities by developing an integrated suite of models representing surface hydrology, groundwater

hydrology, agricultural demands, and river management. This study provides additional tools for water resource managers evaluating future planning activities and potential management actions. Enhanced modeling capacity can have a meaningful impact on real world operational decisions. For example, in 2015, the Nebraska Public Power District entered into an agreement with the Nebraska Game and Parks Commission and Basin Alliance to sell the Spencer Hydropower facility (a senior water right holder). The Nebraska Game and Parks Commission and the Basin Alliance can use modeling capabilities developed in this study to obtain insight into potential operational impacts resulting from a change in beneficial use (i.e., hydropower generation versus instream flow).

## Authority

This Basin Study was conducted as part of the WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. The SECURE (Science and Engineering to Comprehensively Understand & Responsibly Enhance) Water Act of 2009 (Public Law 111-11) and Secretarial Order 3297 established the WaterSMART Program, which authorizes Federal water and science agencies to work with State and local water managers to pursue and protect sustainable water supplies and plan for future climate change by providing leadership and technical assistance on the efficient use of water. Through the Basin Studies, Reclamation works with States, Indian tribes, non-governmental organizations, other Federal agencies, and local partners to identify strategies to adapt to and mitigate current or future water supply and demand imbalances, including the impacts of climate change and other stressors on water and power facilities.

Using Section 9503 of Public Law 111-11 as a guide, Reclamation finalized Directives and Standards (D&S) that outline specific requirements for Basin Studies (www.usbr.gov/recman/temporary_releases/wtrtrmr-65.pdf). According to the D&S, the following elements must be included in Basin Studies: (1) Projections of future water supply and demand, considering specific impacts resulting from climate change; (2) Analyses of how existing water and power infrastructure and operations will perform given any current imbalances between water supply and demand and in the face of changing water realities due to climate change; (3) Development of appropriate alternative and mitigation strategies to meet current and future water demands; and (4) A trade-off analysis of the strategies identified in terms of their ability to meet study objectives.

Federal funding is allocated on a competitive, 50/50 cost-share basis with willing non-Federal entities that must submit an application through an open solicitation process. In Fiscal Year 2010, the State of Nebraska applied for and was allocated a total of $350,000 in Federal funding. Under the Basin Study Program, these funds are used to directly support Reclamation’s joint participation in this study. Funds were matched with non-Federal funds totaling about $500,000. The total cost of the study is $850,000.

## Location and Description of the Basin Study Area

The Basin extends across diverse landscapes from the high plains of eastern Wyoming to its Missouri River termination along Nebraska's northeastern border as shown in figure ES-1. As the river flows east it cuts through the High Plains Aquifer system and principal aquifer units including the Arikaree group and Ogallala group. These two major aquifer formations supply groundwater to numerous irrigation wells and replenish the predominantly aquifer-supplied Niobrara River. A study by Jozsef Szilagyi, et al., (2002) suggests 70 to 90 percent of river flow within the upper reaches of the Basin is attributed to seepage from groundwater. Hundreds of springs flow into the Niobrara River as it travels through the Nebraska Sand Hills. In addition, the Niobrara River collects water from four tributaries including the Snake River, Minnechaduza Creek, Keya Paha River, and Long Pine Creek.


**Figure ES-1.—Niobrara River Basin map.**

## Summary of Federal Features in the Area

There are two Reclamation irrigation projects in the Basin – the Mirage Flats Project and the Ainsworth Unit. Named for the region's deceptive landscape, the Mirage Flats Project is located in Dawes and Sheridan Counties and resides at an elevation around 3,500 feet. The Mirage Flats Project has potential to irrigate 11,662 acres and its main features include Box Butte Dam and Reservoir, Dunlap Diversion Dam, and the Mirage Flats main canal. Downstream from the Mirage Flats Project, the Ainsworth Unit is under the Pick-Sloan Missouri Basin Program and has potential to irrigate 35,000 acres. The Ainsworth Unit's main features consist of Merritt Dam and Reservoir and the Ainsworth Canal. Merritt Dam is located on the Snake River (a Niobrara River tributary). Water stored in Merritt

Reservoir is conveyed in the Ainsworth Canal approximately 40 miles east to project lands near the town of Ainsworth at an elevation around 2,500 feet.

## Existing Water Supply Challenges and Activities

Water management issues in the Basin are complex and represent a long history of involvement by customers and stakeholders in Wyoming, Nebraska, and South Dakota. Surface water supplies serve many uses including irrigation, municipalities, recreation, hydroelectric power generation, and fish and wildlife. Existing water supply challenges are most evident in the Upper Niobrara River Basin (Upper Basin). When this Basin Study began in 2010, the entire Basin held a fully appropriated designation. A fully appropriated designation requires an integrated water management plan within a basin under Nebraska State Law. The goals of the integrated management process are to ensure a balance between water supplies and uses, and to protect the rights of existing users of surface water and groundwater. In June 2011, a Nebraska Supreme Court decision reversed the fully appropriated designation for the Lower Niobrara River Basin (Lower Basin), leaving only the Upper Basin declared fully appropriated.

The Upper Niobrara River is also subject to an interstate compact between Wyoming and Nebraska (States). Established in 1962, the major purposes of the Upper Niobrara River Compact (Compact) are to provide for an equitable division or apportionment of the available surface water supply of the Upper Basin between the States; to provide for obtaining information on groundwater and underground water flow necessary for apportioning the underground flow by supplement to this Compact; to remove all causes, present and future which might lead to controversies; and to promote interstate comity. Within the Compact the States also recognize that the use of groundwater for irrigation in the Basin may be a factor in the depletion of the surface flows of the Niobrara River.

Surface water and groundwater interactions were evaluated in 2004 by the Nebraska DNRs and it was determined that irrigation wells in the UNW region have almost doubled from 1,161 groundwater wells in 1980 to 2,057 groundwater wells in 2004. A moratorium on construction of new wells with a capacity of more than 50 gallons per minute (gpm) was put in place in the UNW in 2004. The Nebraska DNR (2004) study concluded that groundwater use upstream of the Mirage Flats diversion is depleting the groundwater supply and where wells are depleting aquifers in hydrological connection to a river, the wells will cause depletions to streamflow in the river.

## The Need for Federal Involvement

The need for Federal involvement arises primarily from Reclamation's investment in Federal infrastructure within the Basin and Reclamation's related water management authorities. Potential solutions for increasing operational

efficiencies within the Basin may involve use of Reclamation's dams and project infrastructure. Specifically, Reclamation has relationships with the Mirage Flats and AID and expertise operating Box Butte Reservoir and Merritt Reservoir. Reclamation also possesses technical water modeling capabilities and can assist with evaluating water supplies. Federal involvement can help bring together customers and stakeholders to evaluate solutions from a Basin-wide context. With appreciation for past customer and stakeholder efforts to protect water resources in the Basin, it is also important to recognize that Federal participation in this Basin Study endeavors to be unbiased and is non-binding for any partner, particular outcome, or solution.

## Study Purpose and Objectives

This Basin Study is a collaborative effort by the Nebraska DNR and Reclamation to evaluate current and future water supply and demand and to collaborate with stakeholders in the region to identify potential alternative strategies to reduce any identified gaps. The overarching objectives of this study are (1) to evaluate the effects of climate change on future water supplies and demands and (2) to identify potential management actions in the Basin.

The more specific objectives of this study were to:

1. Characterize and quantify the water resources of the Basin;
2. Determine current and future water demands of the Basin;
3. Identify opportunities for meeting water supply needs through structural and nonstructural means such as: surface and aquifer storage and retiming;
4. Evaluate future operations of Box Butte Reservoir and Merritt Reservoir through variable supply conditions; and
5. Analyze the potential effects of climate variability on water supply.

This Basin Study relies on an integrated surface-groundwater model, which was developed to assess the hydrological effects of proposed alternatives aimed at improving Basin resiliency. In addition, an economic analysis was developed to evaluate potential alternative management strategies. Furthermore, this study included an outreach component to better inform stakeholders about river basin characteristics, surface water and groundwater interactions, and potential water management strategies.

## Findings and Conclusions in the Summary

This Basin Study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation,

the Department of the Interior, or the funding partners. This study does not propose or address the feasibility of any specific project, program or plan. Nothing in this study is intended, nor shall this study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in this study represents a commitment for provision of Federal funds.

Through extensive collaboration with the State of Nebraska, modeling tools were developed to provide a consistent representation of hydrology and water operations in the Basin, which helps identify relationships between future management decisions and physical responses in the watershed. It is clear that surface water demands are expected to outpace supply and the path toward implementing potential management actions in the Basin requires further analysis.

## Climate Change Analysis

Climate change scenarios and models were used to evaluate potential impacts on water supply and demand. Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, as opposed to days or weeks. In the climate change analysis, climate data and land characteristics were input to a surface hydrology model (the Variable Infiltration Capacity [VIC] model; Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) to evaluate historical trends and future projections in natural (unmanaged) conditions. The VIC model has limited capability to simulate groundwater dynamics. Simulations using the VIC model are thus intended to provide broad context relevant to large spatial scale changes between historical and future surface water hydrology. An additional set of integrated models, including surface and groundwater hydrology, crop demands, and river operations, were developed for this Basin Study and were used in conjunction with the VIC hydrology model to further explore the impacts of climate change on managed Niobrara River conditions and how alternative strategies may reduce those impacts.

### *Historical Trends*

Historical trends were computed using the Maurer, et al. (2002) meteorological dataset and VIC model simulations. Historical trend analysis over the period 1950-2010 indicates an increasing trend in mean annual temperature and precipitation during this period, along with increases in simulated evapotranspiration (ET) and runoff. Specifically, mean annual precipitation increased approximately 2.2 inches; annual daily average temperature increased approximately 0.6 degrees F; simulated annual ET increased 1.7 inches; and simulated annual runoff increased by approximately 0.6 inches Basin-wide.

### *Baseline Scenario*

A Baseline scenario was developed using historical data to provide a benchmark for evaluating projected climate change effects on natural and managed water in

the Basin. Historical climate over the period 1960-2010 was used to define Baseline scenario climate and natural hydrology. The Upper Basin has experienced groundwater drawdown due to groundwater pumping over the past 50 years. Groundwater declines are reflected in observations made by irrigators as well as maps produced by the University of Nebraska-Lincoln Conservation and Survey Division that document water level changes in Nebraska. Where groundwater wells are hydrologically connected to the river, surface water depletions have led to changes in managed river conditions. Because managed river conditions have changed over the historical record, management conditions in place in 2010 (including irrigated acreage) were held static and used to help define the Baseline scenario. The management conditions are also held constant for future climate change conditions as described below.

VIC model simulations for the Baseline scenario show that mean annual surface water availability is 1.5 inches, where surface water availability is defined as the mean annual difference between precipitation and ET. Mean annual precipitation and temperature under this scenario is 19.6 inches and 47.3 degrees F, respectively, while mean annual ET is 18.1 inches.

***Climate Change Scenarios***

Downscaled Global Climate Change projections used in this Basin Study are based on the Coupled Model Intercomparison Project (CMIP) 3 (World Climate Research Programme's CMIP Phase 3; Meehl, et al., 2007). CMIP3 projections reflect a range of uncertainty relative to future greenhouse gas emissions based on assumptions of future global population and economic growth as well as potential emissions reductions. The future period of 2030-2059 was selected to compare future possibilities to the Baseline scenario. Three climate change scenarios were developed for this study from a set of 112 Bias Corrected Spatially Downscaled climate change projections contained within a CMIP3 archive (Reclamation 2011). The three scenarios are described by their respective water availability characteristics, which reflect the statistical nature of the projection's summer precipitation and temperatures, and are hereafter designated as the Low scenario, Central Tendency (CT) (median), and High scenario.

- **Low scenario**.—Low projected water availability combined with drier summers and greater summer warming.

- **Central Tendency**.—Central projected water availability combined with CT of summer precipitation and temperature.

- **High scenario**.—High projected water availability combined with wetter summers and less summer warming.

The Low, CT, and High scenarios span a range of projected water availability from a modest decrease in mean annual water availability to a substantial increase in mean annual water availability. The fact that the CT projection indicates an overall increase in water availability (10 percent above Baseline) suggests that a

majority of the 112 projections indicate an increase in water availability as opposed to a decrease. However, each of the 112 projections used to derive the climate change scenarios is considered equally likely. All three-climate change scenarios reflect a rise in temperature above the historic mean summer temperature.

## Surface Water Supply

The VIC surface hydrology model was used as the basis for the assessment of surface water supply. The assessment of surface water supply provides a broad view of historical and projected climate (temperature and precipitation), as well as water balance variables including evapotranspiration (ET) and natural (i.e., unimpaired) streamflow. Analysis of water supply and demand gaps in the Basin rely on an integrated suite of models that represent surface and groundwater hydrology, agricultural demand, and river management. The VIC model simulations helped inform this analysis.

As previously described, future temperatures are projected to increase under all three climate change scenarios. Precipitation is projected to decrease under the Low scenario and increase under the CT and High scenarios. Moderately drier conditions in the Low scenario resulted in minor changes in natural runoff while the CT and High scenarios indicate an increase in water availability. As described earlier, management conditions are assumed static at 2010 levels consistent with the baseline scenario development. Climate change scenarios coupled with 2010 management conditions result is an imbalance between water supplies and demands for all scenarios. Results from the integrated model simulations are provided below.

### *Temperature*

Historical mean annual temperature from 1960-2010 is 47.3 degrees F, for the Basin. Comparing the historical temperature to projected temperatures for the 2050s time horizon, the mean annual temperature is projected to rise under all three scenarios — about 5.0, 3.0, and 2.5 degrees F, for the Low, CT, and High scenarios, respectively.

### *Precipitation*

Historically, the Basin has a substantial moisture gradient from west to east; with the western semiarid portion receiving 16 inches mean annual precipitation and the eastern and more humid portion receiving 22 inches mean annual precipitation. Projected changes in mean annual precipitation for the 2050s time horizon will experience a Low scenario precipitation decrease of 3 percent in the eastern part of the Basin and an increase of 2 percent in the western part of the Basin. The CT scenario indicates that the Basin will experience a precipitation increase of approximately 7 to 8 percent. The High scenario indicates a

precipitation increase ranging from 10 to 16 percent, with a greater increase in the eastern part of the Basin.

***Evapotranspiration***

ET by crops and natural vegetation are predominantly influenced by precipitation and temperature. As the Basin experiences greater warming in the future, ET is expected to increase, but will be limited by available moisture. According to VIC model simulations, ET comprises 95 percent of mean annual precipitation, leaving only about 5 percent to surface runoff. Historical mean annual ET ranges from about 15 inches in the western part of the Basin to 20 inches in the eastern part of the Basin from 1960-2010. Projected changes in ET for the 2050s time horizon range from a 1 percent decrease in the Low scenario to an 11 percent increase in the High scenario, both of which occur in the eastern part of the Basin. The CT scenario indicates about a 7.5 percent increase in ET n Basin-wide, primarily as a result of projected increases in mean annual precipitation for the CT scenario. Projected decreases in ET for the Low scenario are due to projected drier conditions, despite projected increases in temperature.

***Streamflow***

The VIC hydrology model is utilized to evaluate potential changes in future runoff and stream flows, relative to the Baseline scenario. Analysis of historical mean annual runoff for the period 1960-2010 indicates the eastern part of the Basin experiences a mean annual runoff of almost 2 inches compared to about 1 inch in the western portion of the Basin. Projected changes in mean annual runoff for the future time period range from about a 9 percent decrease for the Low scenario in the eastern portion of Basin to a 29 percent increase for the High scenario in the western portion of the Basin. The CT scenario indicates an increase in runoff ranging from approximately 11 percent in the eastern portion of the Basin to 15 percent in the western portion.

It should be noted that historical and projected unimpaired streamflow (natural) are not meant to reflect actual flow measured in the Niobrara River and its tributaries. Actual flow may deviate substantially from unimpaired values due to the effects of water deliveries, storage, and other management effects. However, it is presumed that the relative differences between Future scenario and Baseline scenario periods reflect reasonable and comparable differences. Beyond water management actions that are not accounted for within natural runoff projections there are model uncertainties that are also known and assumed to be consistent and thus make results comparable. For example, model bias results in a known shift between modeled seasonal timing and actual seasonal timing. This bias is assumed to exist within the Baseline and Future scenarios making the comparisons valid. Slightly drier projected conditions in the Low scenario produced a shift in seasonal peak flow by approximately one month resulting in unimpaired streamflow that is expected to be within 10 to 30 percent of historic averages (either higher or lower). Projected mean monthly unimpaired streamflow for the CT scenario indicates a substantial increase in seasonal peak flow for all areas analyzed within this Basin Study, on the order of 50 percent within the Upper Basin and on the order of 30 percent for the Lower Basin. In

addition, High scenario streamflow volumes increased for most months of the year with projections increasing from approximately 5 percent to 50 percent or more.

## Water Demand

### Historical Water Demand

Surface water and groundwater resources in the Basin are used primarily for agriculture. The total irrigated area within the Basin is approximately 600,000 acres. Groundwater irrigation accounts for approximately 500,000 acres within the Basin. When surface water is available, the two Reclamation irrigation districts (Mirage Flats Project and Ainsworth Unit) irrigate more than 46,000 acres. In addition, approximately 500 other surface water appropriations are also active in the Basin. Additional water resource uses within the Basin include municipal and industrial (M&I) use, hydropower, recreation, and ecosystem services. Recreation and hydropower are both non-consumptive uses that depend on maintaining a certain flow level in the river.

### Future Water Demand

In the future, irrigation requirements for corn and alfalfa may increase significantly due to increased temperatures in the Basin. The growing season is projected to increase 30 to 40 days by 2100, which could allow for additional crop cycles each year and, hence, a larger water demand on Basin farms. While changes in agriculture development may have an effect on both historic and future imbalances, they were not evaluated in this Basin Study. As has been described above, agricultural and other demands were assumed static at 2010 levels. This approach allows for the evaluation of climate change impacts alone, without being confounded by land use activities such as groundwater development, which have increased since about 1970, or assumptions of future management conditions.

## Gaps between Water Supply and Demand

While surface water irrigated acreage in the Upper Basin has remained nearly level since the mid-1970's, the number of groundwater irrigation wells and associated groundwater acres dramatically increased until 2004 when a moratorium was placed on construction of new wells with a capacity of more than 50 gpm. As analyzed in a Nebraska DNR study on hydrologically connected groundwater and surface water in the UNW NRD (2004), when surface water flows and groundwater aquifers are hydrologically connected, a consumptive use of one depletes the supply of the other.

Water imbalances are demonstrated by surface water shortages in the Upper Basin. For example, during the first few years of operation in the 1950's, the MFID delivered over 15,000 acre-feet of water to farms. Historical records also show that just prior to widespread groundwater irrigation development, MFID consistently delivered between 8,000 and 11,000 acre-feet of irrigation water to its service area. Periods of past robust surface water supply can be contrasted with the more recent period between 2006 and 2015, when surface water deliveries have declined to a level between 1,200 and 4,800 acre-feet. The MFID is not alone in experiencing water supply challenges. Shortages to the Spencer Hydropower facility have also occurred and resulted in halting deliveries to junior surface water appropriators on days when streamflow was insufficient. In addition, recreational users in the National Scenic River reach have observed decreased flows in recent years.

An integrated suite of models was developed and implemented to evaluated gaps in historical and projected water supply and demand. While the VIC model was used to provide a broad view of historical and projected water supply conditions, the water supply information used to estimate gaps included more detailed information about land use within the Basin. Therefore, water supply computed for the gaps analysis differs somewhat from results summarized above as part of the water supply assessment.

Integrated model simulations also suggest average annual surface water demands are expected to outpace supply under all climate change scenarios. As shown in figure ES-2 and studying climate change impacts alone, average annual surface water demands outpace surface water supply by almost 30,000 acre-feet under the Baseline scenario for the fourteen active irrigation areas in the Upper Basin. As the system experiences increases in precipitation (Low to High scenarios) the irrigation demands decrease. Under the Low scenario, the gap is expected to be approximately 35,000 acre-feet. In addition, demands outpace surface water supply for the CT and High scenarios by roughly 27,000 acre-feet and 22,000 acre-feet, respectively (with agricultural demands assumed static at 2010 levels).

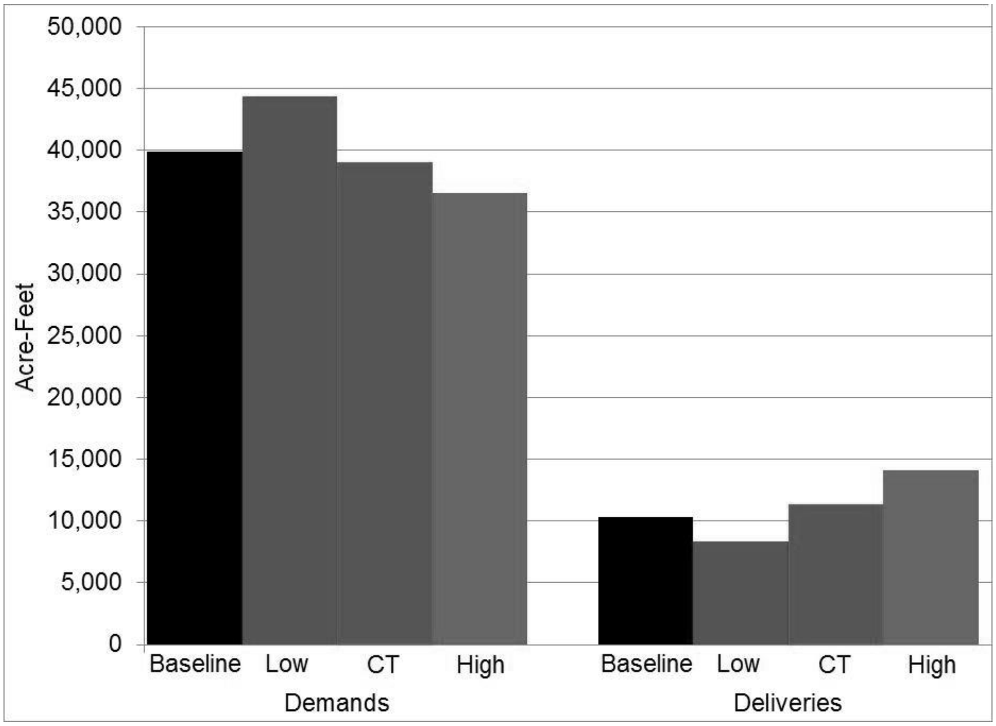


**Figure ES-2.—Average annual surface-water demands and deliveries in the Upper Basin.**

## Future Water Management Alternatives

As a result of the June 2011, Nebraska Supreme Court decision that reversed the fully appropriated designation for the Lower Basin, collaborators for this Basin Study focused on Upper Basin alternatives. The only large-scale irrigation operation in the Upper Basin is the MFID, which relies on releases from Box Butte Reservoir. Lower Basin alternatives were not considered.

An integrated water management model was developed to help assess climate change impacts and evaluate the hydrological effects of proposed alternatives aimed at improving Basin resiliency to water supply and demand imbalances. The integrated water management model consists of three different components: a watershed model for the land/soil water budget, a surface water operations model for Niobrara River operations, and a groundwater model for aquifer response.

The integrated water management model allows for current operational conditions to be simulated as a "No Action" alternative and for comparisons to potential alternative operations. Two proposed strategies deemed "Alternatives" are considered in an effort to explore ways to increase resiliency in the Basin.

- Alternative 1 proposes construction of the Mirage Flats Pumping Station and pipeline, which would reduce canal seepage during surface water delivery leaving more surface water in the system.

- Alternative 2 proposes an operational change by using the Mirage Flats main canal and lateral system to recharge local groundwater.

### Future No Action Scenario

The Future No Action (FNA) scenario compares a Baseline and three climate change scenarios (Low, CT, and High) while maintaining current operational characteristics of Box Butte Reservoir and the Mirage Flats delivery system. Future land use conditions were represented by applying 2010 land use data. Assuming that current operations and land use conditions remain static in the FNA scenario isolates the impacts of climate change.

The FNA scenario compares results for key water budget elements including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge. As expected, results from the FNA scenario suggest Box Butte Reservoir inflows and releases are sensitive to changes in water availability. Therefore, the Low water availability scenario represents the lowest flow; the CT was in the middle; and the High water availability scenario results in the highest flows. Box Butte Reservoir inflows and releases for the Baseline scenario generally reside between the Low scenario and CT scenario. MFID diversions are consistent with Box Butte Reservoir releases.

Under the FNA scenario and even with increased levels of precipitation, the available surface water supply only meets a portion of the crop water demand. Groundwater pumping volumes on co-mingled acreage tend to be inversely proportional to surface water supplies (i.e., increasing surface water supply results in decreasing groundwater pumping). Overall, modeling results show that aquifer recharge levels are also sensitive to changes in water availability with the High scenario producing the greatest aquifer recharge levels and the Low scenario projecting increased aquifer drawdowns.

### Alternative 1 – Mirage Flats Pumping Station

Under current operations, MFID diverts water for irrigation from the Niobrara River at a location downstream from Box Butte Reservoir. Diverted water flows in a main supply canal to a bifurcation for distribution to canal laterals. The canal is unlined and seepage losses are estimated to be at least 30 percent of diverted water. Engineering analysis concluded that canal lining is not viable due to the cost of implementation (IRZ Consulting 2013).

The objective of this proposed alternative is to reduce canal seepage during surface water delivery. Alternative 1 abandons the Mirage Flats diversion and

main supply canal in favor of a new Mirage Flats Pumping Station and supply pipeline. The pumping station would extract water from a high aquifer; essentially making the effect similar to a surface water diversion. The irrigation water would then be would be pumped approximately 1.5 miles north to the bifurcation delivery area which is a more efficient portion of the canal where water can then be delivered to the fields. The ability of Alternative 1 to reduce the impacts of climate change is evaluated by comparing model results from the Baseline and three climate change scenarios (Low, CT, and High) for key water budget elements including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge.

As mentioned, transportation losses are a concern the MFID. Low efficiency canals lose a significant portion of diverted water to seepage during transport. These losses translate to less water being applied to the crop. In Alternative 1, increasing delivery efficiencies for the MFID results in decreasing demands for Box Butte Reservoir releases because less water is lost to seepage in the main supply canal. Therefore, model results suggest that all climate scenarios for Alternative 1 have higher water surface elevations in Box Butte Reservoir than the FNA alternative.

In addition, the Mirage Flats Pumping Station included in Alternative 1 is expected to increase surface water deliveries resulting from increased transportation efficiencies. Increased surface water deliveries help offset supplemental co-mingled groundwater pumping requirements to meet crop water demands. Under all climate scenarios the average volume of co-mingled pumping for Alternative 1 decreased when compared to the FNA alternative. As expected, a change in groundwater recharge for Alternative 1 is concentrated around the MFID. The lack of seepage along the canal system greatly reduced the recharge in this general area, while the irrigated land realized a small increase resulting from increased deliveries.

### Alternative 2 – Mirage Flats Recharge

Alternative 2 consists of the Mirage Flats canal system that would be operated solely as a recharge facility where no irrigation deliveries are made. Water will be released from Box Butte Reservoir, diverted in the Mirage Flats canal system and the lateral system will be used to allow groundwater recharge within the project area. Canal check structures would be operated to hold the canal water at the designed elevation - as if making deliveries. Given no surface water irrigation deliveries are being made under this alternative, it is expected that groundwater pumping will increase.

Alternative 2 compares the Baseline and three climate scenarios (Low, CT, and High) for key water budget elements in the system including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge. Results from the model show Box Butte Reservoir levels that are substantially

higher than the FNA alternative. This is the result of much lower releases for irrigation demands. Alternative 2 is able to meet full groundwater recharge demands for the MFID under all climate scenarios except for the Low climate scenario. In the Low climate scenario, there is not always enough water to divert the full recharge demand. Understanding surface water deliveries in Alternative 2 ceased, irrigators will need to pump additional groundwater. As expected, the average volume of co-mingled pumping for Alternative 2 increased from the FNA alternative for all climate scenarios. Furthermore, significant change in recharge for Alternative 2 is concentrated around the MFID canal system. All climate scenarios result in a significant increase in recharge within the MFID compared to the FNA alternative.

## Economic Analysis

The economic analysis estimates tradeoffs in economic benefits for potential alternatives compared to a scenario with No Action. In addition, the economic analysis evaluates effects of the various climate change scenarios. The scope of this analysis focuses on agriculture and recreation benefits, as these categories are expected to include the majority of river and reservoir related economic benefits associated with this Basin Study’s alternatives.

Agricultural benefits were based solely on the irrigated land within the MFID because it is the only area directly affected by either alternative. The analysis evaluates agricultural benefits, which accrue to the agricultural district under hydrologic conditions specified by each alternative/scenario. Irrigation benefits are measured as a change in net farm income received from the use of irrigation water to produce agricultural commodities (Reclamation, 2004a).

A collection of Federal, State, and private land ownership along the river affords relatively good access for recreation opportunities in the Basin. A separate study prepared by the University of Nebraska - Omaha (2009) analyzed the economic and social values of recreation on the Niobrara River and suggests visitations increase when surface flows are higher. In contrast, periods of drought or low flows can jeopardize the quality of the recreational experience resulting in fewer people on the river and negative effects for the local economies.

Recreation benefits are based on reservoir recreation models developed for Box Butte and Merritt Reservoirs and a river recreation model developed for the most heavily used stretch of the designated Niobrara National Scenic River. To estimate recreation economic benefits under each alternative/scenario for the river and reservoir settings, the analysis estimated annual visitation and the value per visit.

Net benefits under the FNA alternative with climate change (i.e., Low, CT, and High) exceed the Baseline No Action (BLNA) alternative without climate change.

It is assumed that recreation will increase when temperatures and reservoir levels are higher. Net benefits are dominated by the recreational benefits, which increase under each FNA climate change scenario due to increased temperatures under all three scenarios and increased water elevation under the CT and High scenarios. Agricultural benefits are minimal compared to recreational benefits and range from 8 percent to 12 percent of the combined benefit for the alternatives/scenarios. Under each climate change scenario, the net benefits of Alternative 2 exceed those of Alternative 1. With the exception of the Alternative 1 Low scenario, proposed action alternatives/scenarios result in positive net benefits ranging from $1.0 to $14.2 million when compared to the FNA alternative/scenarios.

The only cost included in this analysis is a $4.46 million estimate for construction of the Mirage Flats Pumping Station proposed in Alternative 1. Annual operation, maintenance, replacement, and power (OMR&P) costs are beyond the scope of this analysis, but would be an important component of further analysis for both Alternative 1 and Alternative 2. For example, while Alternative 2 may present groundwater recharge benefits at no additional construction cost, this Alternative would require additional study to account for the full range of OMR&P costs related to increased pumping. In addition, a change in Mirage Flats canal system operations may require review of potential water right implications for the MFID and needs further evaluation.

In summary, benefits of both Alternative 1 and Alterative 2 generally exceed a No Action scenario and suggest both strategies have potential to be considered in future studies. Alternatives 1 and 2 have not been undertaken because there are a number of implementation hurdles that require additional study. First, there is uncertainty associated with projected climate scenarios as positive economic benefits rely heavily on an assumption that recreation will increase when temperatures and reservoir levels are higher. Second, a change in Mirage Flats canal system operations may present water rights implications for the MFID requiring further review. Third and finally, OMR&P costs were not factored in the economic analysis for Alternative 1 and Alternative 2 and these costs will likely decrease the potential for either alternative to be economically viable.

## Basin Study Limitations

The watershed model used in the integrated suite of models to simulate soil water balance has limited representation of some physical processes such as snowpack dynamics. This Basin Study's watershed model attempts to account for these items through an iterative calibration process with the groundwater model; however, further calibration may be necessary. The watershed model is also intended to assist in large scale planning projects. Using this Basin Study to employ crop management techniques for a specific location may not be effective because this study is intended to represent the system as a whole.

An in-depth analysis of endangered species responses to climate change was determined to be an undertaking outside the scope of this Basin Study. According to the U.S. Fish and Wildlife Service (USFWS), fourteen species within the Basin are currently protected under the Endangered Species Act (ESA). This study does not explore vulnerabilities of endangered species as affected by climate change. However, this study may be a useful resource for researchers focusing on ESA and State designated species.

Finally, the tradeoff analysis focuses only on agricultural and recreational benefits. Agricultural benefits are based solely on irrigated land falling within the boundaries of MFID and results are not extrapolated to total Basin irrigated acreage. From a cost perspective, changing operations under proposed action alternatives could result in different annual OMR&P costs. However, OMR&P costs were not evaluated in this Basin Study's economic analysis. Thus, cost differentials are preliminary and based purely on construction costs.

## Conclusion

The overarching objectives of this Basin Study were to identify the effects of climate change on future water supplies and identify potential management options in the Basin. This study relies on a series of models to assess hydrological effects of potential alternatives aimed at improving Basin resiliency. This study confirms that the Niobrara River faces a range of potential future imbalances between water supply and demand. Addressing such imbalances may require additional analysis and may not be resolved through any single approach or alternative.

Through collaboration with key stakeholders, this Basin Study elevates regional water planning efforts to new levels and offers sound science that can be used as a foundation for long-term planning efforts focusing on sustaining the balance between water uses and water supplies. Specifically, integrated models developed in this Basin Study are a useful resource that can assist Basin stakeholders as they continue coordinated efforts to improve system reliability and develop strategies that address the Basin's needs. For example, information from this Basin Study may be used to help inform future planning efforts related to the Basin-wide Management Plan, Integrated Management Plan modifications, and future changes to river operations.

Projected water availability was evaluated using both historical data and climate change scenarios (Low, CT, and High), and could range from a modest decrease to a substantial increase. Future temperatures are projected to increase under all three climate change scenarios. In addition, precipitation is projected to increase for the CT and High water availability scenarios. Slightly dryer projected conditions in the Low scenario produced modest changes in unimpaired

streamflow while the CT and High scenarios indicate a substantial increase in seasonal peak flow. Average annual surface water demands are expected to outpace supply under all climate change scenarios.

Potential management actions were evaluated in an effort to address the gap between water supply and demand. Alternative 1 would include a structural change with construction of the Mirage Flats Pumping Station, which would reduce canal seepage during surface water delivery leaving more surface water in the system. Alternative 2 proposes an operational change by using the Mirage Flats main canal and the lateral canal system to recharge local groundwater. Both alternatives result in Box Butte Reservoir levels that are higher than the FNA alternative due to increased canal delivery efficiencies in one scenario and lower irrigation diversions in the other scenario. Furthermore, both options show potential for future consideration as additional analysis in the Basin is conducted.

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## Acronyms and Abbreviations

| | |
|---|---|
| % | percent |
| °F | degree Fahrenheit |
| afd | acre-feet per day |
| AID | Ainsworth Irrigation District |
| Basin | Niobrara River Basin |
| Basin Study | Niobrara River Basin Study |
| BCA | benefit-cost analysisBLNA Baseline No Action Alternative |
| C | Candidate (ESA) |
| CENEB | Central Nebraska subregion |
| cfs | cubic feet per second |
| CMIP | Coupled Model Intercomparison Project |
| Compact | Upper Niobrara River Compact |
| CT | Central Tendency (median) |
| D&S | Directives and Standards |
| DNR | Department of Natural Resources |
| E | Endangered (ESA) |
| *E. coli* | *Escherichia coli* |
| ES | Executive Summary |
| ESA | Endangered Species Act |
| ET | evapotranspiration |
| FA1-Low | Future Action Alternative 1-Low |
| FA1- High | Future Action Alternative 1-High |
| FA2-CT | Future Action Alternative 2-CT |
| FNA | Future No Action Alternative |
| FY | fiscal year |
| gpm | gallons per minute |
| IPAC | Information for Planning and Conservation |
| Lower Basin | Lower Niobrara River Basin |
| M&I | Municipal and Industrial |
| MODFLOW | MODular three-dimensional finite-difference groundwater FLOW model (USGS) |

| | |
|---|---|
| MFID | Mirage Flats Irrigation District |
| NE | Nebraska |
| NPPD | Nebraska Public Power District |
| NRD | Natural Resources District |
| NSS | native species status (Wyoming) |
| NSS1 | ranking of extremely imperiled (Wyoming) |
| NSS2 | ranking of severely imperiled or extremely vulnerable (Wyoming) |
| NSS3 | ranking of severely vulnerable (Wyoming) |
| NSS4 | ranking of moderately vulnerable or stable with severe limiting factors (Wyoming) |
| NSSU | ranking of status unknown, additional information needed (Wyoming) |
| OMR&P | operation, maintenance, replacement, and power |
| Reclamation | Bureau of Reclamation |
| River | Niobrara River |
| RBM | River Basin Model |
| SD | South Dakota |
| SE | species endangered |
| SECURE | Science and Engineering to Comprehensively Understand & Responsibly Enhance (Federal) |
| SGCN | Species of Greatest Conservation Need (Wyoming) |
| States | Interstate compact between Wyoming and Nebraska |
| T | Threatened (ESA) |
| TMDL | total maximum daily loads |
| Upper Basin | Upper Niobrara River Basin |
| UNW | Upper Niobrara-White River region |
| U.S. | United States |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| VIC | Variable Infiltration Capacity |
| WaterSMART | Sustain and Manage America's Resources for Tomorrow |
| WWCRA | West-Wide Climate Risk Assessments |
| WY | Wyoming |

# Contents

## Figures

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# I. Introduction

## A. Purpose, Scope, and Objectives of this Basin Study

This Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (DNR) and the Department of the Interior's (DOI) Bureau of Reclamation (Reclamation). Its purpose is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the Niobrara River Basin (Basin) to identify potential alternative strategies to reduce any identified gaps. This Basin Study has been conducted as part of the DO I's WaterSMART Program.[1] Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessments (WWCRA) (Reclamation, 2011 and 2015), but contains additional information, if available.

This Basin Study has produced an integrated surface-groundwater model to assess the effects of management options on hydrology, an economic analysis to evaluate the economic effects of those management options, and forums for public education and outreach. This study has also advanced the knowledge of Basin hydrology, aquifer characteristics, and surface-groundwater interactions. The hydrologic and economic analyses will help both State and local water management entities assess the costs and benefits of various proposed management options. The education and outreach component of this study has provided opportunities to educate those within the Basin area about the Niobrara River, the underlying aquifer, water management strategies, and the implications of current and potential management options.

The overarching objectives of this Basin Study were (1) to identify the effects of climate change, climate variability, and projected future water supplies and demands, and (2) to evaluate potential management actions that may be taken to retime or rebalance water supplies and demands.

The more specific objectives of this study were to:

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[1] The WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program was established by the Secretary of the Department of the Interior under Secretarial Order 3297 to address an increasing set of water supply challenges, including chronic water supply shortages due to increased population growth, climate variability and change, and heightened competition for finite water supplies. The Program is authorized under the SECURE (Science and Engineering to Comprehensively Understand & Responsibly Enhance) Water Act of 2009 (Public Law 111-11). Through WaterSMART, Reclamation is making use of the best available science in the assessments it conducts and the policies it employs, with the goal of securing future water supplies.

6. Characterize and quantify the water resources of the Basin;

7. Determine current and future water demands of the Basin;

8. Identify opportunities for meeting water supply needs through structural and nonstructural means such as: surface and aquifer storage and retiming;

9. Evaluate future operations of Box Butte and Merritt Reservoirs through variable supply conditions; and

10. Analyze the potential effects of climate variability on water supply.

This Basin Study has integrated results from groundwater, surface water, and watershed models to evaluate future water supply scenarios resulting from: (1) climate change/variability; and (2) depletions from groundwater development. These results have been used in conjunction with an economic analysis to assess the relative benefits and economic viability of the two proposed management alternatives for the operation of irrigation canals in the Mirage Flats area.

## B. Location and Description of the Basin Study Area

The Basin extends across diverse landscapes from its origin on the High Plains of eastern Wyoming to its terminus at the Missouri River near Niobrara, Nebraska. The river is approximately 535 river miles in length and drains an area of 12,600 square miles of northern Nebraska and adjacent parts of Wyoming and South Dakota (figure 1). Temperature and precipitation vary greatly along the Basin from one end to the other, from winter to summer, and sometimes from day to day.

Current uses within the Basin include approximately 600,000 irrigated acres, municipal use (approximately 20,000 people), hydropower, recreation, and wildlife. In 1991, a 76-mile stretch of the River was designated as the Niobrara National Scenic River, just downstream from the Fort Niobrara National Wildlife Refuge. Within Nebraska, the Basin has two Reclamation projects for irrigation: the Mirage Flats Project (11,662 acres) and the Ainsworth Unit (35,000 acres). The Basin has one hydropower facility, Spencer Hydropower Plant.

Near its origin in southeastern Wyoming, the Niobrara River cuts through the water-bearing Arikaree Formation. As it bends through Sioux, Dawes, and Sheridan counties in Nebraska, it gradually begins to run over the more prolific Ogallala Formation. Replenished by seepage from various formations, the Niobrara River is a predominantly aquifer-supplied river. Data developed by Szilagyi, et al., (2002) found that, in the River's upper reaches, 70 to 90 percent of its flow can be attributed to seepage from groundwater. Since the late 1800s, the Niobrara River has been a significant source of water for water-rights holders along its banks. In 1948, the Box Butte Reservoir and canal system,

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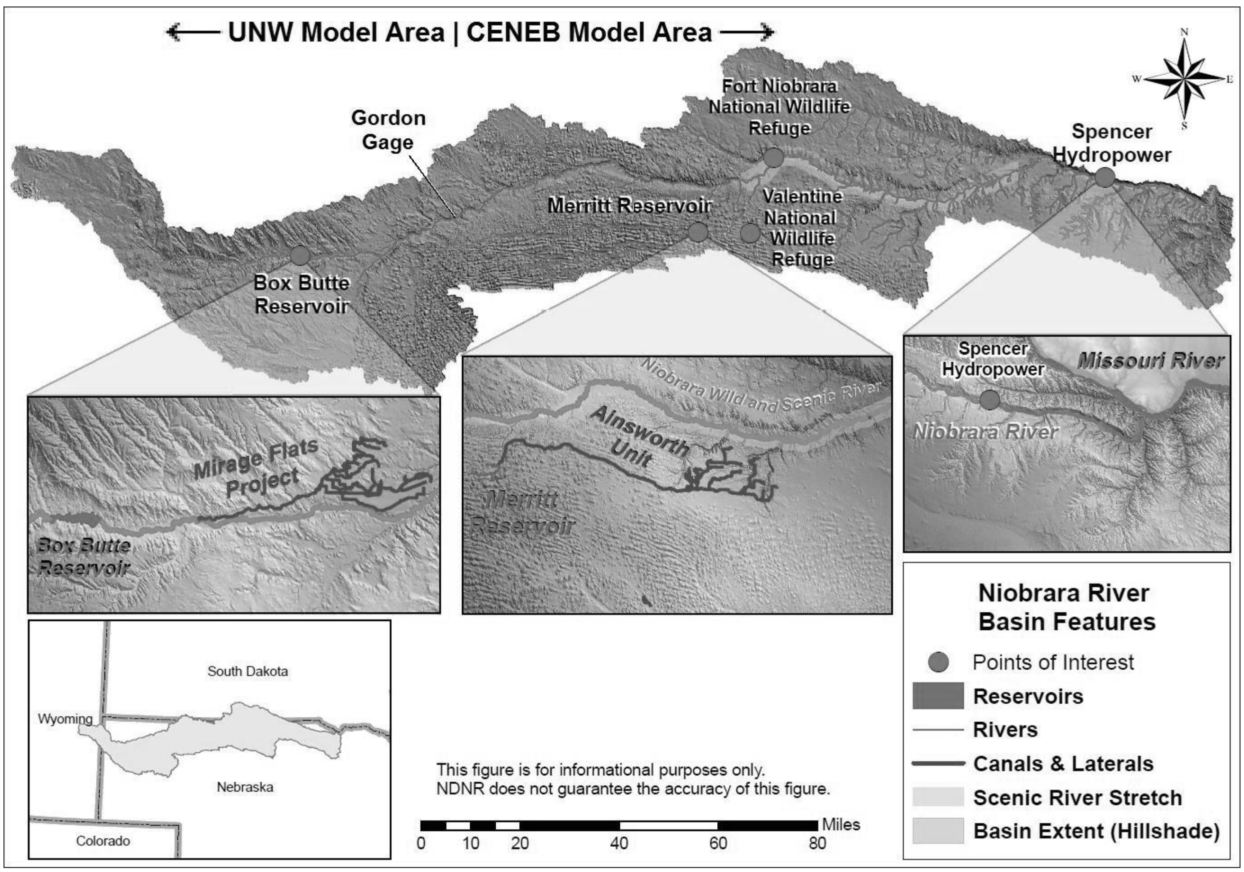


**Figure 1.—Location of Niobrara River Basin.**

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completed by Reclamation, began to provide irrigation for the Mirage Flats Irrigation District (MFID).

## C. Collaboration and Outreach

The Upper Niobrara River (Upper Basin) Basin Study was established under the DOI's WaterSMART Program as a partnership between Reclamation, the Nebraska DNR, and the Upper Niobrara-White (UNW) Natural Resources District (NRD). From the outset, this study attracted interest and support from numerous stakeholders in and near the Basin. Stakeholder agencies and organizations that have been involved in this Basin Study include:

Federal:

- Reclamation
- National Park Service

U.S. Fish and Wildlife Service (USFWS)
State:

- Nebraska DNR
- Nebraska Game and Parks Commission
- Wyoming State Engineer's Office

Local and Other:

- Ainsworth Irrigation District (AID)
- Lower Niobrara NRD
- Middle Niobrara NRD
- Mirage Flats Irrigation District (MFID)
- Nebraska Public Power District
- Niobrara Council
- Upper Elkhorn NRD
- Upper Loup NRD
- Upper Niobrara-White (NRD)

Representatives from most of these organizations attended the Basin Study Kickoff Meeting on July 19, 2011, and a Mid-Point Informational Meeting on August 8, 2012. Both meetings were held at the Niobrara Lodge in Valentine, Nebraska.

Public information about the Basin Study Project has been provided on-line by Reclamation (http://www.usbr.gov/WaterSMART/bsp/studies.html) and by Nebraska DNR (http://www.dnr.ne.gov/iwm/niobrara-river-basin-study-update). In addition, Brandi Flyr of Nebraska DNR provided a public presentation about the Basin Study Project on January 23, 2013, as part of the University of Nebraska's Nebraska Water Center Spring Seminar series (http://watercenter.unl.edu/SpringSeminars/SpringSeminarSeries.asp).

## D. Interrelated Activities

The Niobrara River Compact (Compact) is an agreement between the States of Wyoming and Nebraska regarding the waters of the Upper Niobrara River. The major purposes of this Compact are:

- To provide for an equitable division or apportionment of the available surface water supply of the Upper Basin between the States;
- To provide for obtaining information on groundwater and underground water flow necessary for apportioning the underground flow by supplement to this Compact;
- To remove all causes, present and future which might lead to controversies; and
- To promote interstate comity.

The responsibilities for flood control, soil erosion, irrigation run-off, and groundwater quantity and quality issues within Nebraska are designated to 23 NRDs, which together cover the entire State. NRDs are local government entities with broad responsibilities for protecting natural resources. Generally, major Nebraska river basins form the boundaries between NRDs. Three NRDs cover the area of the Basin — the UNW NRD, Middle Niobrara NRD, and Lower Niobrara NRD. These three districts were important collaborators in conducting this Basin Study and developing the alternatives considered.

An effort was made, in the development of alternatives, to balance competing uses, so that the existing domestic, agricultural, environmental, recreational, commercial, and industrial activities are preserved to maintain the economic viability, social and environmental health, safety, and welfare of the Basin for both the near- and long-term while maintaining Nebraska's compliance with the Compact.

This Basin Study also provides valuable information to be utilized in the ongoing efforts to develop a Basin-wide integrated water planning document.

# II. Climate Change Analysis

## A. Background

The climatic setting of the Basin is similar to that of the State of Nebraska overall. Nebraska is well known for its climate extremes and for having a substantial moisture gradient from west to east, with the western portion being semiarid (16 inches of average annual precipitation) and the eastern portion being more humid (22 inches of average annual precipitation). As one example of its differences in seasonal climate, about 40 percent of mean annual precipitation falls from May through July, while only 5 to 7 percent falls from December through February. In addition, the State experienced widespread droughts in the 1930s and 1950s, while the last 50 years have generally been wetter than prior to the 1950's.

Nebraska has experienced an overall warming trend of about 1 °F since 1895, with greater warming in winter and spring (2.0 °F in the December–February time period and 1.8 °F in March–May). The length of the frost-free season in Nebraska has increased by more than one week since 1895 (University of Nebraska-Lincoln, 2014). Although it is difficult to attribute historical precipitation variability to human-induced change (Hoerling et al., 2010), there is growing evidence of a linkage between the warming of the globe, arctic sea ice decline, and extreme winters across the Great Plains Region (Reclamation, 2013).

WWCRA projections of future climate (Reclamation, 2011) indicate that the Great Plains Region will continue to experience recurring wet and dry cycles spanning periods of years to decades, as it has throughout its history. Climate change, however, is expected to exacerbate hazards such as tornadoes, droughts, floods, and to increase economic losses in the future (University of Nebraska-Lincoln, 2014). According to Nebraska's climate change impacts assessment (University of Nebraska–Lincoln, 2014), projected changes in temperature for the State range from 4 to 9 °F by the late 21st century (2071to 2099). Projected changes in temperature and precipitation are expected to coincide with a decreasing trend in spring snow water equivalent, a decreasing trend in April–July runoff volume, increasing trends in December–March with annual runoff volumes and reduced soil moisture levels (Reclamation, 2013).

The future climatic and hydrologic regime in the Basin will impact, to varying degrees, certain environmental resources pertinent to this Basin Study, including water resources, agriculture, aquatic ecosystems, invasive species, and other related resources. In some years, irrigators may face restrictions on the amount of water that can be applied to their fields. By the year 2100, according to the Third National Climate Assessment (Shafer et al., 2014), the frost-free season will increase by 30 to 40 days for Nebraska. The assessment also suggests that crop growth cycles have already been altered as a result of warming winters and

changes in rainfall timing and magnitude. As these trends continue, they will require new agriculture and livestock management practices (Shafer et al., 2014).

## B. Data and Models Used to Evaluate Climate Change Effects on Water Supply

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, rather than days or weeks. Projections of future climate and hydrologic conditions developed under WWCRA (Reclamation, 2011) were used as the basis for the climate scenarios considered in this Basin Study.

- **Water Management Alternatives.—**This Basin Study uses various models to evaluate the watershed's response to projected future climate conditions and to water management alternatives. Three future climate change scenarios, using a time horizon of 2030–59, were developed to encompass a range of projected climate and water availability conditions.

  These scenarios, further described in Appendix A, generally represent:

  1. A hotter and drier future climate that results in low projected water availability (hereafter called the Low scenario)

  2. A future climate representing the Central Tendency (CT) of all available global climate model projections, which features a middle range of projected water availability (hereafter called the CT scenario)

  3. A wetter and less warm future climate having high projected water availability (hereafter called the High scenario). Together, the climate change scenarios are intended to represent a range of projected future conditions.

  The selected Low scenario corresponds with a decrease in water availability, Basin-wide, of approximately 77,000 acre-feet. The selected CT scenario corresponds with an increase in water availability of approximately 53,000 acre-feet. The selected High scenario corresponds with an increase in water availability of approximately 290,000 acre-feet.

- **Climate Change Scenarios.—**This Basin Study explores the impacts of the three selected climate change scenarios (Low, CT, and High) on the current level of development and water demands (set to 2010 levels) in comparison with historical climate. These three scenarios, along with the historical condition, have been named for consistency throughout this Basin Study summary report and appendices. The combination of the observed historical climate with current levels of development and current

water management practices is termed the Baseline No Action (BLNA) scenario. The scenarios that combine the three projected future climates with current levels of development and current water management are termed the Future No Action (FNA) scenarios (Low, CT, and High).

- **Potential Management Alternatives.—**This Basin Study also explores two potential management alternatives under the same future change scenario data and assumed future demands. Alternative 1 consists of changing the location where water is diverted from the Niobrara River to the MFID, in order to reduce conveyance losses in the current canal system. Alternative 2 involves using the existing canal systems to recharge (move the surface water downward to the ground water) the groundwater system and to discontinue all surface water delivery. These alternative scenarios are termed Future with Alternative 1 (Low, CT, and High) and Future with Alternative 2 (Low, CT, and High).

- **Future No Action Scenarios.—**Together, the three FNA scenarios are used in this study to evaluate how climate change might impact current water management. The Future with Alternative scenarios are used to evaluate how the operational alternatives may reduce projected water supply/demand gaps identified by the FNA scenarios.

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# III. Water Supply and Demand

## A. Historical Water Supply

Typical flows in the Niobrara River are around 5 cubic-feet-per-second (cfs) near the Wyoming-Nebraska State line, around 15 cfs at the gage at Agate in Nebraska, and between 20 and 40 cfs at the gage above Box Butte Reservoir. The records from the stream gages upstream of Box Butte Reservoir show indications that the streamflow has been decreasing over time. An analysis by the Nebraska DNR (2004) showed that the amount of surface water available for diversion from the River upstream of the Mirage Flats canal diversion has continued to decrease since the project was completed. At the State line, the 5-year annual average flow decreased by 567 acre-feet from the 1956–60 time period to the 1996–2000 time period. Between 1946 and 2001, the average annual flow above Box Butte Reservoir decreased by 4,332 acre-feet (figure 2). Records also show that diversions to the Mirage Flats Canal averaged 19 percent less per year during the 28 years from 1976 through 2003 than during the previous 28 year time period (1948–75).

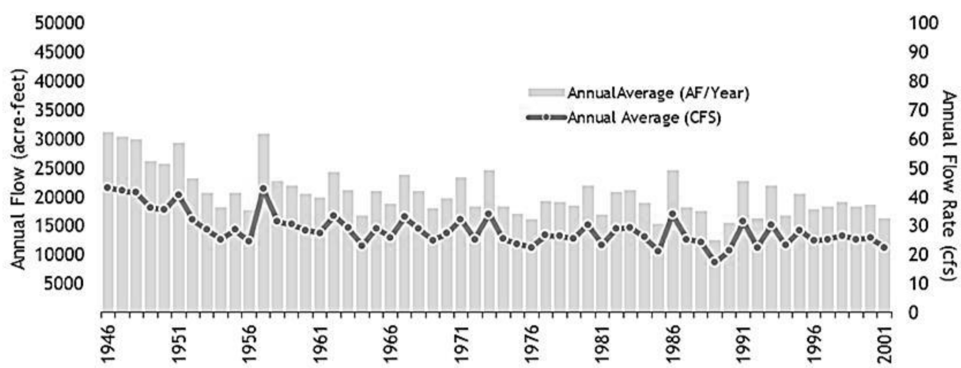


**Figure 2.—Average annual flow of the Niobrara River above Box Butte Reservoir.**

The Variable Infiltration Capacity (VIC, described in detail in Appendix A) model was applied to the historical period 1950–2010 to quantify historical trends in surface water availability. The VIC model is an advantageous tool for this type of evaluation since this model has been applied over the continental United States (U.S.) and beyond, and is the basis for the WWCRA assessments (Reclamation, 2011). Mean annual temperature and precipitation have increased over the period of 1950–2010, as have evapotranspiration (ET) and runoff. Historical trends computed as part of this Basin Study are generally consistent with historical trends reported by the University of Nebraska-Lincoln (2014) study and with trends found by Reclamation's 2013 Literature Synthesis. Table 1 summarizes computed historical trends in mean annual precipitation, temperature, and runoff.

**Table 1.—Historical Climatic Trends Computed from VIC Model Simulations for the Time Period of 1950–2010**

| Parameter | Basin-wide Change | Percent Change |
|---|---|---|
| Annual Precipitation | + 2.2 in | + 12% |
| Daily Average Temperature | + 0.56 °F | -- |
| Annual Runoff | + 0.55 in | + 45% |

## B. Future Water Supply

### 1. Surface Water

Climate changes are likely to result in an increased frequency of drought and heat waves. Combined with increased human demand for water, these conditions will result in lower streamflows and an increase in the frequency of de-watered stream segments and dried-up wetlands (University of Nebraska-Lincoln, 2014).

Historical and projected changes in climate and water balance variables are summarized for each of the three climate change scenarios developed for this Basin Study: Low, CT, and High. Together, the climate change scenarios are intended to represent a range of projected future conditions.

Projected changes Basin-wide show that mean annual precipitation would decrease by about 2 percent under the Low scenario, but increase under both the CT and High scenarios (about 8 and 14 percent, respectively). Mean annual temperature would rise under all three scenarios — about 5.0, 3.0, and 2.5 °F, respectively, for the Low, CT, and High scenarios. Mean annual runoff would decline about 8 percent under the Low scenario but increase as much as 13 and 27 percent in the CT and High scenarios, respectively. Refer to Appendix A, table A-7 for additional details.

Assessment of future water supply includes the analysis of changes in unimpaired streamflow, as computed by the VIC model, and of changes in the managed water supply at various locations in the Basin, including Reclamation's two reservoirs, Merritt and Box Butte. Historically, unimpaired streamflow in the Basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Projected mean monthly unimpaired streamflow for the CT scenario indicates a substantial increase in seasonal peak flow for all Basin Study model nodes, on the order of 50 percent in the Upper Niobrara River Basin (Upper Basin) and on the order of 30 percent for the Niobrara River near Spencer, Nebraska. For the low flow season (generally defined as August through November), reductions in mean monthly unimpaired flow on the order of 10 to 20 percent are projected for the CT scenario.

Results for the Lower Niobrara River Basin (Lower Basin) show streamflows would be the lowest under the Low climate scenario and significantly higher

under the High climate scenario. Compared to historical baseline flows, the Burge, Sparks, and Spencer gages would show average decreases of 46, 17, and 8 percent, respectively, under the Low scenario. Flows at these three points would increase under the other two climatic scenarios: 32, 11, and 15 percent for the CT scenario; and 87, 36, and 34 percent for the High scenario.

Simulations of current (2010 level) water management indicate only modest impacts to Merritt Reservoir operations under the CT and High future scenarios. Under the Low scenario, however, the reservoir levels at the end of the summer months would be on average 2 feet lower than projected for the Baseline, CT, or High modeled scenarios.

## 2. Groundwater

Overall, the groundwater modeling results show that baseflow and groundwater levels are sensitive to future projected climatic change. Across almost the entire Basin, climate scenarios of High and Low water availability can increase or reduce the baseflow and groundwater levels, respectively. Figure 3 shows a time series of baseflow between the Gordon and Sparks gages as it might have been if each of the modeled climate scenarios had been in effect during the period of 1960–2010. The actual historical baseflows during that period are shown for comparison. Also shown in figure 3 are the High and CT water availability scenarios that both lead to higher baseflow, and the Low scenario corresponds to lower baseflow. In addition, modeling results show that baseflow on this part of the River would have increased throughout this period under the CT and High water availability scenarios, but would have decreased under the Low water availability scenario.

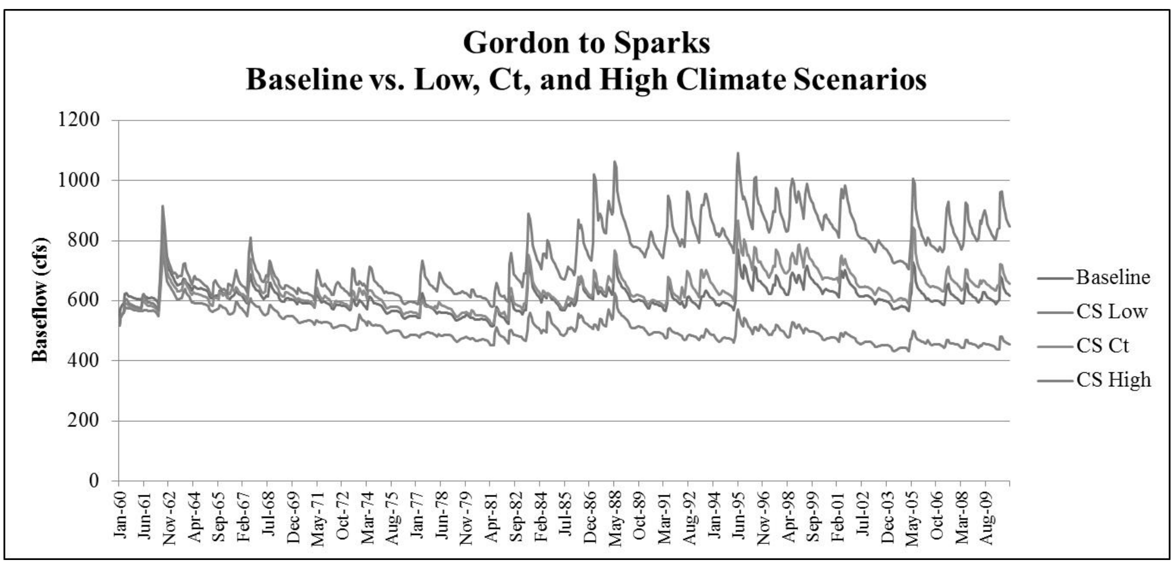

**Figure 3.—Gordon to Sparks reach baseflow comparison – climate scenarios of baseline, Low, CT, and High without management operations (1960-2000).**

The effects of the modeled climate scenarios on standing groundwater levels are well exemplified by the projections for Box Butte County, Nebraska. Groundwater levels there have been declining for decades and are expected to decline further under Low water availability, but to rebound under CT or High water availability (figure 4). The patterns of change in groundwater levels follow similar patterns in the Mirage Flats area.

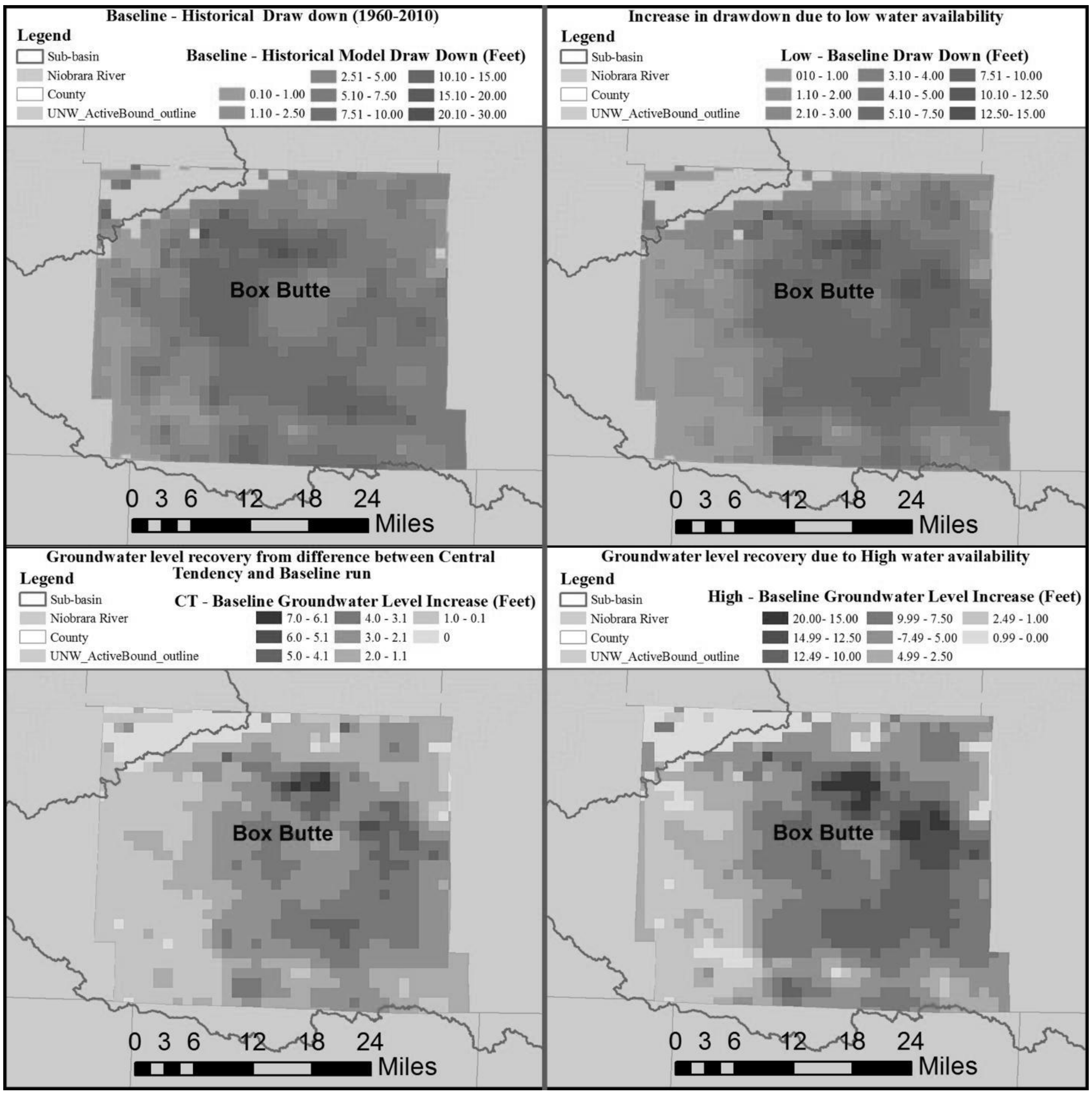

**Figure 4.—Groundwater drawdown comparison in Box Butte County for baseline, Low, CT, and High scenario model runs with no change in management operations.**

The patterns of change in groundwater levels in the Central Nebraska (CENEB) subregion area (figure 5) follow patterns similar to those of the Box Butte Reservoir and Mirage Flats Reservoir area for different climate scenarios except in the low water availability scenario. In the lower portion of the Sparks to Spencer sub-basin, groundwater levels did not change under this climate scenarios. It is noted that the Baseline scenario consistently shows reduced baseflow (figure 3) and groundwater levels (figures 4 and 5). This is because all scenario analyses assume constant historic land use conditions maintained as of year 2010 for the purpose of isolating the impacts of land use change.

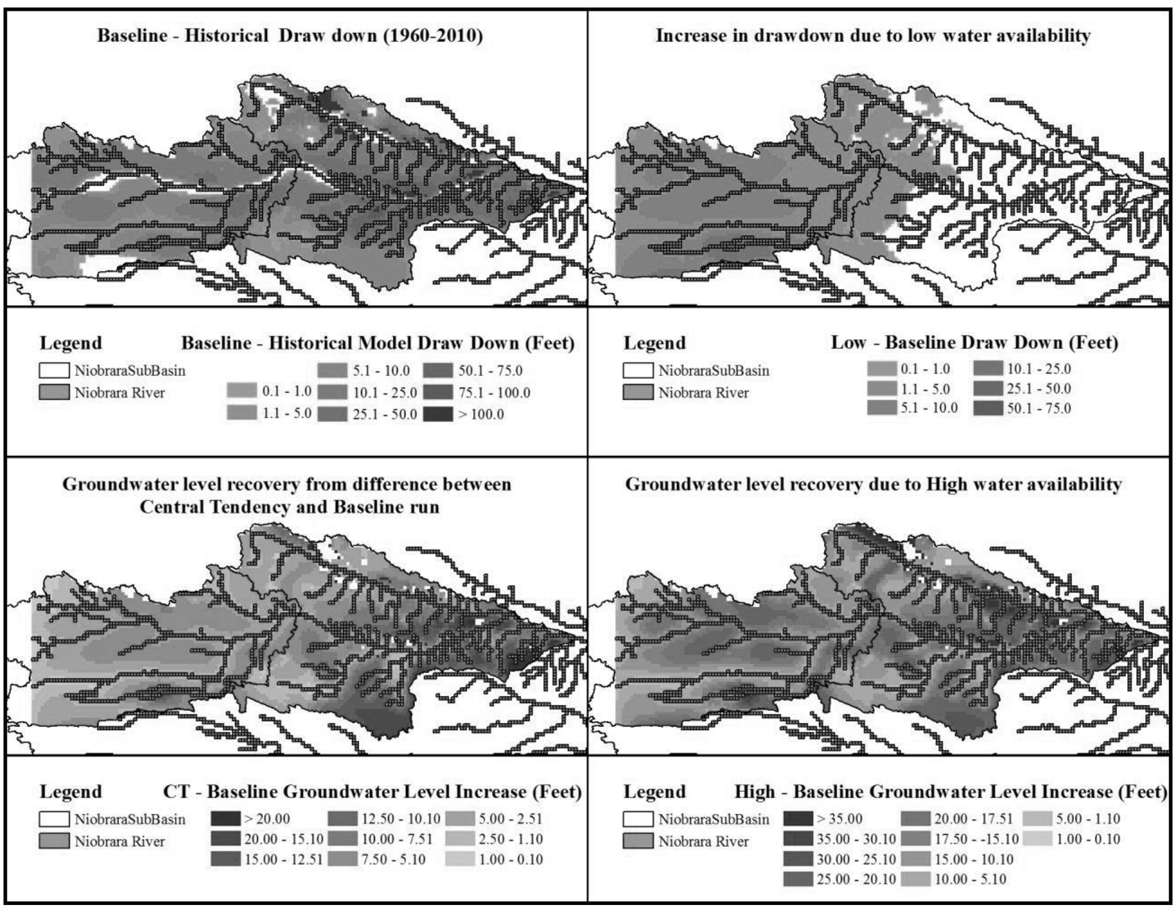


**Figure 5.—Groundwater level change comparison in the CENEB model area under baseline, Low, CT, and High scenario model runs with no change in management operations.**

### 3. Watershed Model Simulation Results

Generally, the modeling results show changes in climate will influence the water balance within the watershed. Increases in precipitation decrease the need for irrigation and increase the ET, recharge, and runoff contributions to streamflow. Table 2 describes the absolute change in the water balance of the two modeled areas under the various climate scenarios. In the UNW area, which has a relatively meagre supply of surface water, the increases in precipitation projected under the High and CT climate scenarios would yield more available surface water and, hence, would reduce the volume of groundwater that needs to be pumped.

**Table 2.—Average Percent Change in Water Balance Parameters from the Baseline Climate in the Basin**

| Climate Scenario | Precipi-tation | Groundwater Pumping | Surface Water Deliveries | Total Applied Water | ET | Recharge | Runoff Contributions to Streamflow |
|---|---|---|---|---|---|---|---|
| **UNW Area (upstream of the Gordon Gage)** | | | | | | | |
| Low | –16.12% | 9.35% | –11.01% | –14.47% | –13.72% | –27.12% | –23.08% |
| CT | 6.35% | –4.35% | 17.46% | 5.69% | 4.96% | 15.03% | 10.95% |
| High | 18.89% | –11.50% | 42.75% | 17.00% | 13.66% | 63.60% | 46.23% |
| **CENEB Area (from Gordon Gage to Spencer Gage)** | | | | | | | |
| Low | –9.36% | –0.37% | –0.37% | –9.17% | –8.69% | –13.40% | –3.34% |
| CT | 7.03% | –5.21% | –5.06% | 6.77% | 4.17% | 24.22% | 12.40% |
| High | 13.49% | –6.41% | –6.27% | 13.07% | 7.31% | 52.10% | 26.07% |

The watershed model covers a large area and the results are available in several different resolutions. Appendix E provides an overview of the modeling results and investigates the changes due to climate and alternatives at various resolutions.

## C. Historical Water Demand

In the Basin, surface water and groundwater resources are primarily used to supply water for agricultural. However, additional uses of the Basin's water resources include municipal, hydropower, recreation, and ecosystem use.

Surface water and groundwater resources in the Basin are used primarily for agriculture. The total irrigated area within the Basin is approximately 600,000 acres. Groundwater irrigation accounts for approximately 500,000 acres within the Basin. When surface water is available, the two Reclamation irrigation districts (Mirage Flats Project and Ainsworth Unit) irrigate more than

46,000 acres. In addition, approximately 500 other surface water appropriations are also active in the Basin.

Withdrawals for municipal and industrial (M&I) use are relatively minor in the Basin, totaling only about 3,500 acre-feet per year. Recreational activities (i.e., boating, fishing, etc.), especially on the National Scenic River reach, are a key component of local economies. A recent survey of outfitters and other River users (Whittaker, et al., 2008) found that most of the users prefer maintaining a flow range of 600–900 cfs (at least through the summer recreation season) to achieve an optimal recreational experience. Hydropower, like recreation, is a non-consumptive use that depends on maintaining a certain flow level in the River. Total water demand of the Spencer Hydropower Plant is 2,035 cfs or 4,037 acre-feet per day.

## D. Future Water Demand

If temperatures increase during the growing season and precipitation decreases, as indicated by the Third National Climate Assessment (Shafer et al., 2014), rural water supplies will be more vulnerable to shortages due to competition from irrigation. Irrigators may face allocation restrictions that set limits on the amount of water that can be applied each year. The assessment suggests that rising temperatures are leading to increased demand for water and energy. In parts of the Basin, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs. By the year 2100, the assessment also indicates that the frost-free season will increase by 30 to 40 days for Nebraska (Shafer et al., 2014).

The Synthesis and Assessment Product by the U.S. Climate Change Science Program (Lettenmaier et al., 2008) discusses the effects of climate change on agriculture and water resources (Hatfield et al., 2008). Findings suggest significant irrigation requirement increases for corn and alfalfa due to increased temperatures and carbon dioxide and reduced precipitation. Further, agricultural water demand could decrease due to crop failures caused by pests and disease exacerbated by climate change. On the other hand, agricultural water demand could increase if growing seasons lengthen and, assuming that farming practices could adapt to this opportunity, by planting more crop cycles per growing season. However, a shift toward earlier planting dates may not be viable due to the continued vulnerability to freeze damage in the spring (University of Nebraska-Lincoln, 2014). For example, the 2012, 2013, and 2014 growing seasons produced hard freeze conditions during the first half of May, even as favorable soil temperatures are occurring two weeks earlier when compared to the early 1980s. If precipitation amounts remain steady or decrease by the year 2100, ET demand will result in less moisture available to grow crops during their critical reproductive periods that occur in May (wheat), July (corn), and August (sorghum, soybean). During 2012, native vegetation broke dormancy a month

earlier than normal and soil moisture reserves were depleted across most of the mid-western U.S. corn belt well before the critical pollination period was reached.

There are no current plans to increase the water supply demands at the Spencer Hydropower Plant. However, if low flows become common in the future, junior surface water users will likely to be administered more often to meet the flow requirements of the Spencer Hydropower Plant. The entire Basin upstream of the Spencer Hydropower Dam is now subject to stays on new surface water appropriations and on new high-capacity wells in areas hydrologically connected to the Niobrara River.

No increase in M&I demand was modeled in this study; there are no indications that that this type of demand will change significantly in coming decades. Furthermore, it is currently such a minor component of total demand within the Basin (a fraction of a percent), that the overall water budget of the Basin would not be greatly affected even if M&I demand were to double. An additional source of demand could potentially come from the Nebraska Game and Parks Commission, which has undertaken studies to decide whether to pursue an instream flow right in the Basin.

## E. Gaps between Water Supply and Demand

A primary objective of this Basin Study is the quantification of shortages in available surface water. For the 14 active irrigation areas included in the UNW model, average annual surface-water demands outpace supply by almost 30,000 acre-feet under the Baseline climate (figure 6). This gap is even larger under the projected Low climate scenario, but progressively smaller under the CT and High scenarios. Even under the High scenario, though, there is still a deficit of more than 22,000 acre-feet. Supplemental groundwater pumping can make up some of that deficit, but not all.

Other imbalances within the Basin are represented by the shortages that have been realized during recent drought conditions by MFID, the Spencer Hydropower Plant (a nonconsumptive use), and junior surface water diverters. In addition, recreational users in the Niobrara National Scenic River reach have noted decreased flows in recent years.

The MFID was completed in 1948 and initially delivered 16 inches per acre to its service area, but the water supply had diminished to 7 inches per acre by 2000. Recent drought conditions have resulted in deliveries of only 4 inches per acre. In contrast, the water supply of the AID has been very reliable and stable throughout the history of the project. AID draws its supplies from Merritt Reservoir, a Reclamation project along the Snake River (Wyoming), a tributary to the Niobrara River. The Snake River flows have been fairly constant under recent climatic conditions.

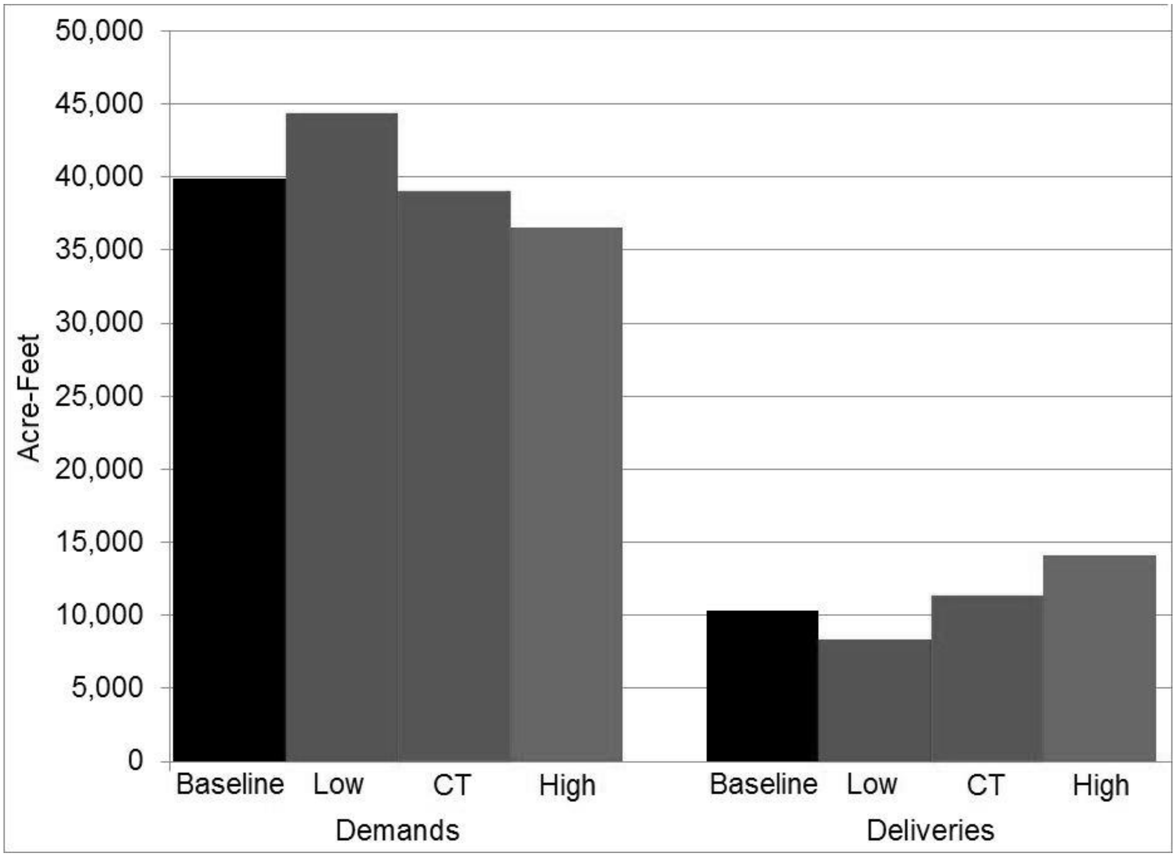


**Figure 6.—Average annual surface-water demands and deliveries in the UNW area under the Baseline and three projected future climates.**

Shortages to the Spencer Hydropower Plant, owned by Nebraska Public Power District (NPPD), resulted in halting deliveries to upstream junior surface water users on days when streamflow was insufficient. Junior surface water users may elect to enter subordination agreements with NPPD to diverter the water to the Spencer Hydropower Plant like the agreements made with MFID in 1943, and with AID in 1964. Subordination agreements allow junior users who choose to diverter be able to utilize their water rights during periods of flow shortage in exchange for just compensation to NPPD. These agreements are necessary to provide junior diverters water to meet crop irrigation requirements, but shortages remain.

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# IV. Development of Alternative Strategies

When this Basin Study was undertaken in 2010, the entire Basin held a fully appropriated designation, which required the three responsible NRDs (UNW, Middle Niobrara, and Lower Niobrara) to implement integrated management operation plans for their respective areas in the Basin. In June 2011, the Nebraska Supreme Court issued an opinion that compelled DNR to reverse the fully appropriated designation for the Lower Basin, leaving the Upper Basin still declared fully appropriated. This eliminated the mandatory requirement for the Middle and Lower Niobrara NRDs to implement integrated management plans. As a result, the collaborators for this Basin Study did not see a need to develop operational alternatives in the Lower Basin and focused their attention on Upper Basin alternatives.

The only large-scale irrigation operation in the Upper Basin is the MFID. MFID diverts water from the Niobrara River at Reclamation's Dunlap Diversion Dam, approximately 14 miles downstream of Box Butte Reservoir (figure 7). Diverted water flows down the main canal and is delivered to a bifurcation for distribution to the canal reaches. The main canal is unlined and seepage losses are estimated to equal approximately 30 percent of the diverted water. Additionally, flow through the main canal is restricted by voluminous sediment deposits. Seepage from the canal results in high groundwater levels at some locations; however, the groundwater also returns into the canal system, providing flow at times when it would otherwise be empty. Furthermore, 12 bridges, used primarily for farmer access that cross the canal system, are in poor condition. In order to address these problems, MFID commissioned a preliminary study (IRZ Consulting 2013). That study presented three management action plans (alternatives) for solutions to the problems with the main canal.

In that study the first alternative was to line the canal with geomembrane over a cushion of geotextile and to cover it with concrete for protection. Reclamation estimated that the cost of this alternative, for the lining alone, was approximately $5 million, and that cost does not include underdrain systems or easements for discharge back to the Niobrara River. This alternative also would only resolve the seepage losses and would not address concerns with sediment deposition in the canal system nor the farm bridges that need reinforcement or reconstruction.

In that study the second alternative was to relocate the diversion point of the Mirage Flats pumping station 12 miles downstream of the original location with a discharge pipeline running to the canal diversion area. This alternative would substantially reduce the length of the canal to the diversion point and would reduce seepage and evaporative losses, sedimentation, siphoning issues, and the high groundwater table.

In that study the third alternative was to use the canal primarily as a groundwater or an aquifer recharge canal during high flows and to discontinue all surface water delivery. Irrigators would make up for the loss of surface water through additional pumping from the recharged aquifer. This alternative would address all of the concerns except for sedimentation.

Based on preliminary scoping, the canal lining alternative was not deemed viable due to the cost of implementation and its inability to address all of the aforementioned problems with the exception of seepage losses. Hence, the study evaluated only the pumping station relocation (here redesignated Alternative 1) and use of the existing canals for aquifer recharge (Alternative 2).

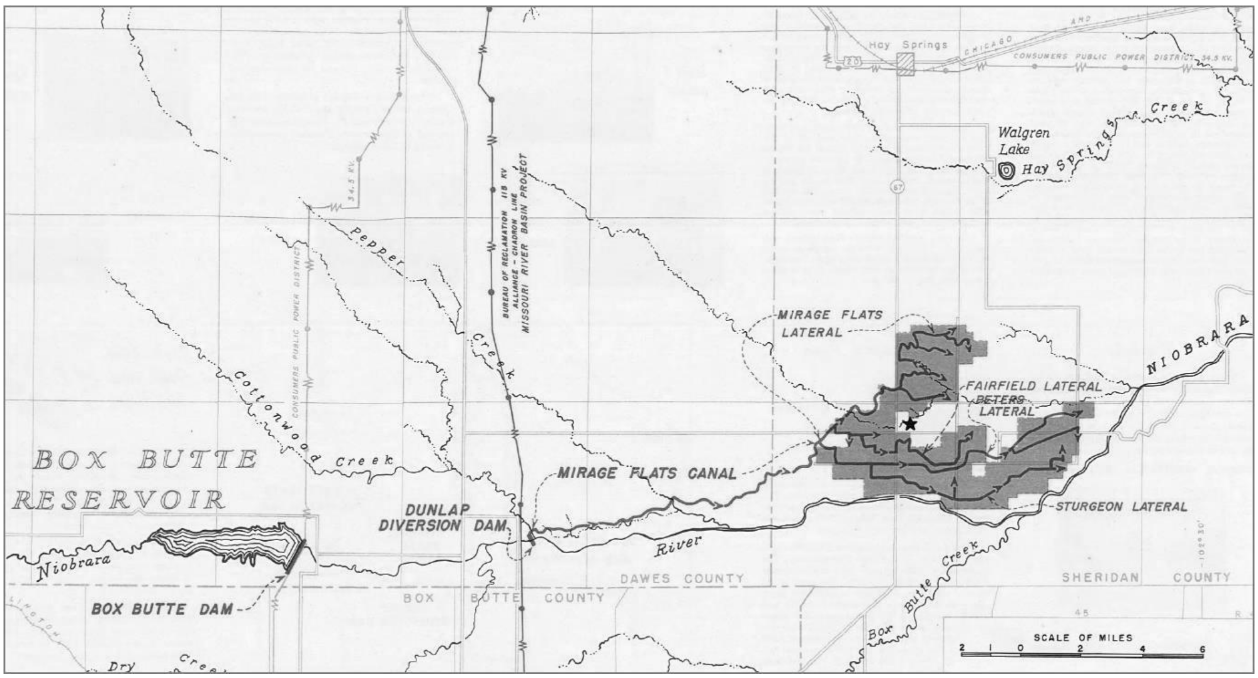

**Figure 7.—Map of the MFID (from the original Reclamation project map, 1954).**

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# V. Modeling of Alternatives

## A. Overview of Models

Three different models were selected for this Basin Study. The Watershed Model, the Groundwater Model, and the Surface Water Operations Model for both the UNW and CENEB Regions. These models were linked to form integrated models designed to present a dynamic representation of the total water budget for the Niobrara River. The three modeling tools selected to simulate the three primary parts of the hydrologic cycle (figure 8) are land, river, and aquifer. The integrated models provide decision makers with reliable quantitative information about the hydrologic consequences of alternative water management strategies.

Information generated in one model can be used as input to or as a calibration target for another model. As currently structured, users pass results from one model to another. A simplified illustration of how this data exchange works in the two subregions is shown in figure 9. The primary elements of information exchanges are:

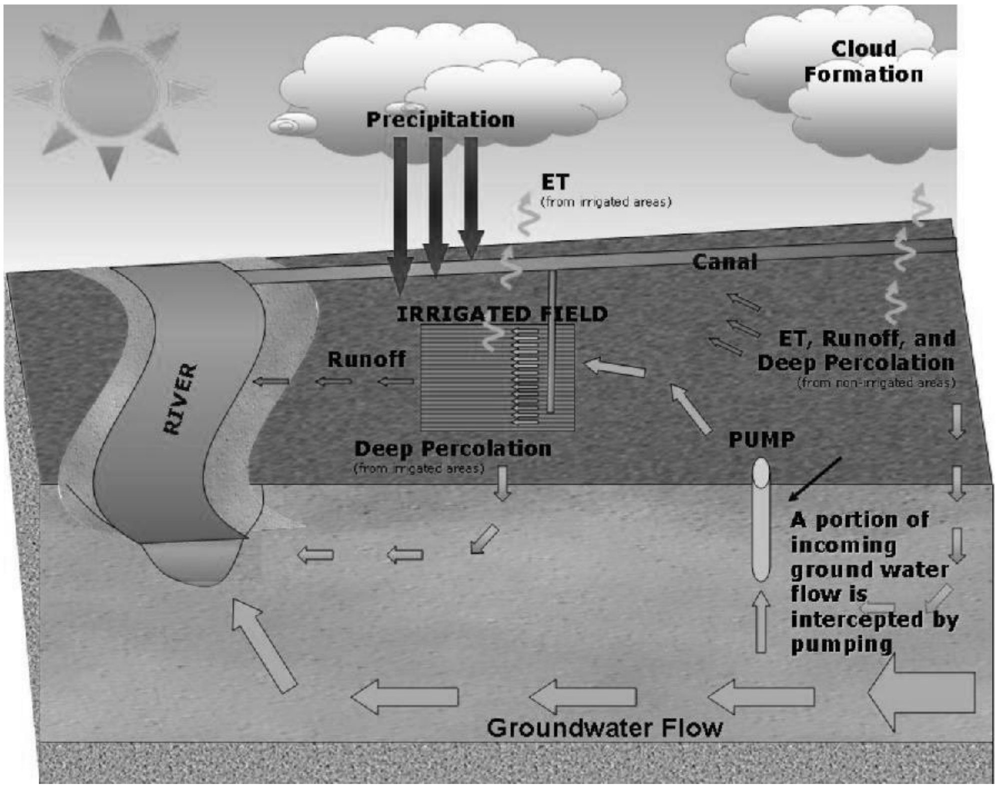
- Water diversions in the Surface Water Operations Model and well pumping in the Groundwater Model are taken from outputs of the watershed model.

- Recharge to the Groundwater Model is taken from the Watershed Model for deep percolation from the land, and from the Surface Water Operations Model for canal seepage. The stream routing in the Groundwater Model requires inputs from the Surface Water Operations Model.

- The Surface Water Operations Model gains runoff as calculated by the Watershed Model, and baseflow as calculated by the Groundwater Model. Streamflows can be lost to the Groundwater Model if the River stage (analyzing how much water is moving in the River) is higher than the underlying water table.

Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and the transfer of results between the models. This approach is considered a "passive" linkage. The primary purpose of integration is to use outputs from the watershed and groundwater models as inputs into the surface water operations model. Inputs into the water operations model form a dynamic representation of the total water budget of the Niobrara River. Thus, streamflow estimates are the integrated results of all three models.

Appendix F presents more information on the detailed sequence of the integrated models for the UNW and CENEB.




Notes:

1. The Watershed Model was used to represent the land/soil part of the cycle. The objective of a land/soil Watershed Model is to calculate water demands for irrigation, and the fate of rainfall and applied water on the land. This requires use of a method to simulate the soil water balance as a function of climate, soil, and land use.
2. The Surface Water Operations Model was used to represent the river part of the cycle. The objective of a Surface Water Operations Model is to route flows down the Niobrara River and to simulate the storage, release, diversion, and use of water along the River and the canal system that draw from the River. This requires a method that can replicate operation of the system (reservoirs and canals) and routing of water to meet surface water demands.
3. The Groundwater Model was used to represent the aquifer part of the cycle. The objective of a Groundwater Model is to quantify changes in aquifer water levels (water in storage) resulting from recharge to and pumping of the aquifer; and representation to simulate the effects of pumping on baseflow contributions to streamflow, and predict subsurface flows in and out of this Study area. The primary requirement is knowledge of aquifer properties and stream connections.

**Figure 8.—Illustration of a hydrologic cycle showing alternatives models and the significance of irrigation.**

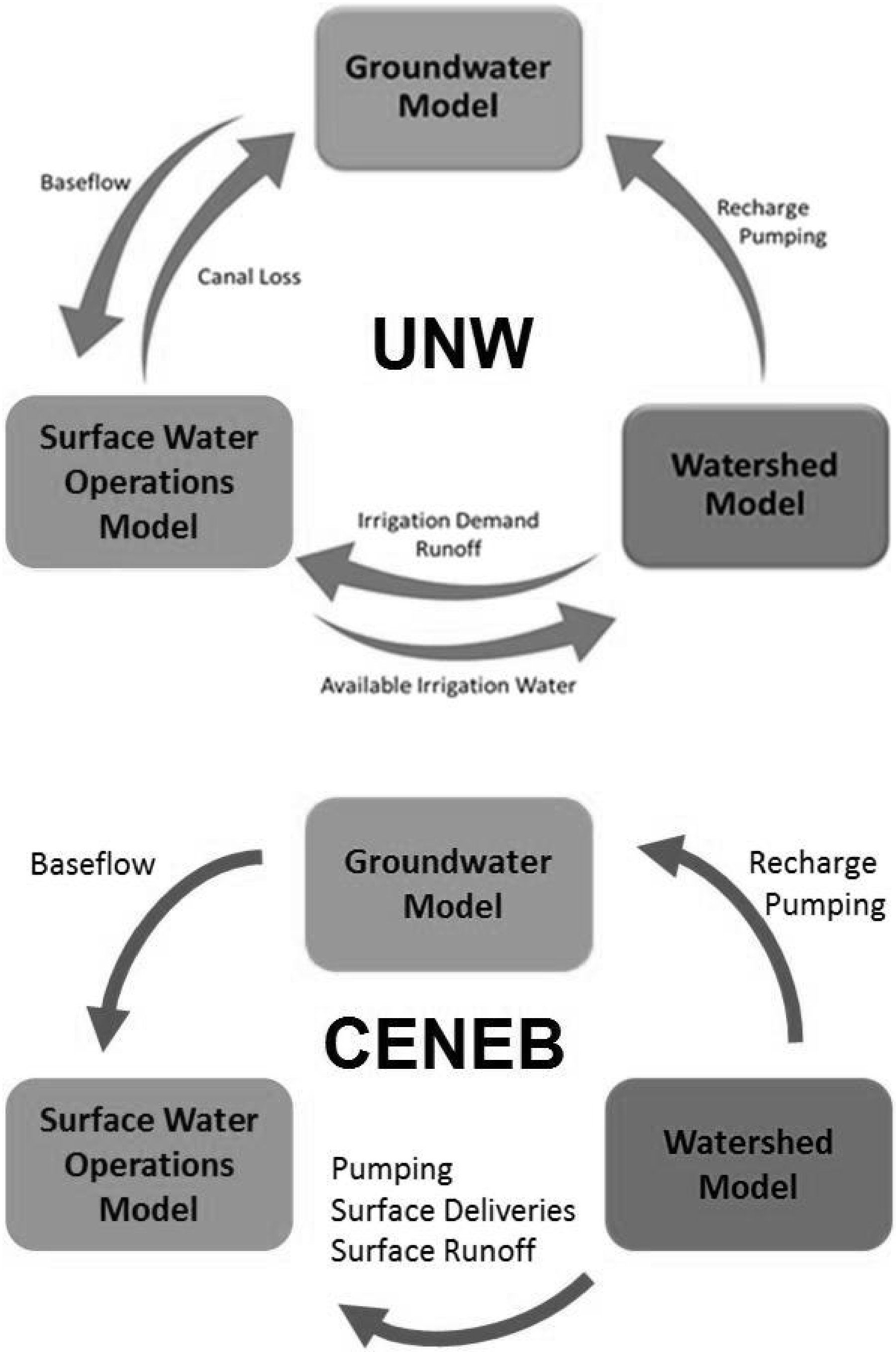



**Figure 9.—Linkage of individual models within the integrated models for the UNW and CENEB subregions.**

## B. Surface Water Operations Model

Surface water operations were modeled separately for the UNW and CENEB subregions. For the UNW subregion there was already an existing surface water operation model that was used for this Study. The CENEB subregion Surface Water Operations Model was created by Reclamation. Both regional models were developed to simulate the storage, release, diversion, and use of water along the Niobrara River and the canals that draw from the river.

### 1. Upper Niobrara White Region Surface Water Operations Model

The UNW Surface Water Operations Model simulates the present-day surface water components of the Niobrara River system from the Wyoming-Nebraska State Line to the Gordon Gaging Station in Nebraska (including reservoirs, the River, and canals), and to calculate the water budget terms of these components for the surface water operations system.

Appendix C details how this model was set up, calibrated, and operated.

### 2. Central Nebraska Region Surface Water Operations Model

A Surface Water Operations Model, including the operations of Merritt Reservoir, was developed by Reclamation's Nebraska-Kansas Area Office for the CENEB Region to simulate managed flows in the Niobrara River and to evaluate the effects of projected surface and groundwater hydrology on streamflows within the CENEB. Inputs to the CENEB surface water operations model primarily consist of baseflow (output from the groundwater model), deliveries from surface and groundwater sources (output from watershed model), and surface runoff (output from the watershed model). Additional inputs to the model include total streamflow at the Gordon Gaging Station, the model's upstream boundary location, and simulated inflows and ET at Merritt Reservoir.

Appendix D details how this model was set up, calibrated, and operated are available in.

## C. The Groundwater Model

There were two existing groundwater models by Reclamation that covered the different coverage areas of the Basin. The UNW Groundwater Model covered only the UNW area, whereas the CENEB Groundwater Model covered the Middle and Lower Basin area. For time and efficiency purposes, the determination was made to utilize these two groundwater models for this Study instead of creating a different model covering all of the Basin.

Groundwater flows were modeled separately for the Upper Basin (UNW region) and the Lower Basin (CENEB Region). Both area models extended beyond the geographical limits of the Basin's surface water, to account for subsurface flow into and out of the Basin. Both models were constructed using variants of the U.S. Geological Survey's (USGS) MODFLOW (MODular three-dimensional finite-difference groundwater FLOW model) Program. MODFLOW-2000 (Harbaugh, et al., 2000) was selected for the UNW area, and MODFLOW-2005 (Harbaugh, 2005) was applied to the CENEB area.

Both models divide their respective areas into 1-mile by 1-mile grid cells, sufficient to understand the general hydraulics of each region, and is supported by the amount of observational data recorded over several decades. Although the available data is sparse for some portions of the UNW Region, such as parts of the Sand Hills and areas just east of the State Line, many of the key areas for analysis (Box Butte County and the MFID) have sufficient data to support this spatial resolution.

The groundwater models each simulate a time period of several decades, extending from the approximate onset of groundwater irrigation in their areas up until recent years. The time spans modeled were from1960 to 2010 in the UNW area, and from1940 to 2011 in the CENEB area.

Each Groundwater Model began with a postulated steady-state condition to represent ongoing "stresses" to the groundwater system (i.e., inflows, outflows, water-table levels, etc.) prior to the start of the modeling period. The subsequent time span as a series of "stress periods" was then added to the model. Either known or estimated values were provided for inflows, outflows, river stages, groundwater pumping, etc., at the start of each stress period. In the CENEB Groundwater Model, annual stress periods were simulated from 1940 through 1985, and then monthly intervals were used for the period from 1986 through 2011. The UNW Groundwater Model used monthly intervals throughout its modeled period of 1960 to 2010.

The time frame of model simulation described here is for the original Groundwater Model versions calibrated to the historic observed data. Future time periods were modeled using climate change data where 1) the Baseline Model was run from 1960 to 2010 with historic weather data and constant 2010 land use data throughout, and 2) the future climate projection (future time period) was run (Low, CT, and High) with 2010 land use data throughout. Then the results from future climate change runs were compared with the results of the baseline runs.

Appendix B details how the groundwater models were set up, calibrated, and operated.

# D. The Watershed Model

The primary role of the Watershed Model is to ensure that the water supplies and water uses have been accounted for within a balanced water budget. The water budget is represented by precipitation, applied irrigation water, ET, deep percolation, runoff, and change in soil water content.

Historically, watershed models have only interacted with the corresponding groundwater models. This Basin Study introduced the interaction of the Watershed Model with the Surface Water Operations Models. Surface water irrigation data were developed to pass surface water demands, supplies, and canal recharge between the Watershed Model and the Surface Water Operations Model (Appendix F) to allow projecting more accurate streamflow estimates.

## 1. UNW and CENEB Subregions

The watershed models used in this Basin Study include all the lands that drain to the Niobrara River, from its headwaters in eastern Wyoming to the stream gage near Spencer, Nebraska, roughly 12,300 miles in a primarily agricultural setting. The UNW Watershed Model covers an area that includes the western portion of the Niobrara River, as well as some surrounding lands. It is situated largely in the northern half of the Nebraska panhandle, ranging from the eastern Wyoming headwaters area to the Sheridan-Cherry County (Nebraska) border. This area consists of 8,700 miles, of which 4,800 miles drains to the Niobrara River. The eastern portion of the Basin falls within the domain of the CENEB model.

The CENEB Watershed Model covers nearly 34,500 miles in north-central Nebraska, ranging from the panhandle in the west to the confluences of the Loup and Platte Rivers, the Elkhorn and North Fork of the Elkhorn Rivers, and the Niobrara and Missouri Rivers in the east. The Watershed Model extends to the Platte River in the south and covers the extent of the Niobrara drainage area in the North. Of this area, approximately 7,500 miles drains to the Niobrara River upstream of the Spencer Gaging Station in Nebraska.

## 2. Model Alternatives for this Basin Study

For use in this Basin study, the Watershed Model incorporated the climate data developed by Reclamation (Appendix A). Four climate scenarios (Baseline, Low, CT, and High Scenarios) were created to represent both historical and possible future conditions under varying levels of water availability.

Two proposed management alternatives were investigated under each climate scenario:

1. The Mirage Flats Pumping Station Alternative proposed bypassing a relatively inefficient portion of the MFID's canals by moving the MFIDs diversion point nine miles downstream and installing a high-aquifer well field.

2. The Mirage Flats Canal Recharge Alternative proposed ceasing surface water irrigation deliveries and converting MFID to groundwater. MFIDE would continue to divert water during the growing season, allowing the water to seep from its canals as recharge, to mitigate the effect of the increased pumping.

Either of these alternatives, if implemented, would be a long-term project. Therefore, information on the viability of either management plan under all of the projected climate change scenarios is critically important. To address this concern, the watershed models were updated to project future conditions. All aspects of the models were developed to represent historical conditions and were updated to current (2010) values using the model representing that specific water component. These parameters include land use, irrigation development, M&I pumping, and application efficiencies, as well as crop characteristics and management practices. The current values were applied to the entire time span represented by the model. The integrated water management modeling procedure ensures that changes performed in separate models, including the surface water operations models, are incorporated as input or output into the entire system represented in the Groundwater, Surface Water Operations, and Watershed Models.

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# VI. Economic Analysis

## A. Purpose, Scope, and Objectives

Please note, the economic analysis is preliminary in nature and its limitations do not allow it to be relied on for the implementation of a construction project.

An economic analysis was performed as part of this Basin Study to provide a comparison of the net economic benefits of the proposed alternatives under a series of climate change scenarios. The alternatives propose operational and structural modifications designed to recharge aquifers and conserve surface water in the Basin. The scope of the economic analysis is limited to agriculture and recreation, as these categories are expected to include the majority of river- and reservoir-related economic benefits associated with this Study's alternatives. Therefore, the primary objective of the economic analysis was to estimate the net economic benefits for each proposed alternative as compared to the No Action Alternative based on benefits accruing only to agriculture and recreation. A secondary objective was to evaluate the economic effects associated with the various climate change scenarios. The results of the economic analysis are presented in section VII.C.

## B. Alternatives Analyzed

This Economic Analysis evaluates the costs and benefits of two proposed operational alternatives under three projected climatic scenarios, as explained in Appendix G. In addition, four versions of the No Action Alternative were developed for comparison purposes, with one based on historical climate/hydrologic conditions (without climate change) and the other three based on the future climate change scenarios. Baseline No Action Alternatives (BLNA) present historical climate with no climate change and no operational modifications.

The FNA Alternatives represent the following:

- Future climate change scenario 1 (hot/dry) with no operational modification (FNA Low)

- Future climate change scenario 2 (median) with no operational modification (FNA CT)

- Future climate change scenario 3 (warm/wet) with no operational modification (FNA High)

Table 3 displays the three alternatives associated with each climate change scenario plus the BLNA for a total of 10 alternative/scenario combinations used for comparison purposes within this economics analysis.

**Table 3.—Alternatives and Climate Change Scenarios Analyzed**

| Period | Alternative/Operational Modification | Climate Change Scenario | Designation |
|---|---|---|---|
| Baseline | No Action (current operations) | Historical (no climate change) | Baseline No Action |
| Future | No Action (current operations) | Low water availability | Low No Action |
| Future | (1) Mirage Flats pumping station | Low water availability | Alt 1 Low |
| Future | (2) Mirage Flats canal recharge | Low water availability | Alt 2 Low |
| Future | No Action (current operations) | Central Tendency | CT No Action |
| Future | (1) Mirage Flats pumping station | Central Tendency | Alt 1 CT |
| Future | (2) Mirage Flats canal recharge | Central Tendency | Alt 2 CT |
| Future | No Action (current operations) | High water availability | High No Action |
| Future | (1) Mirage Flats pumping station | High water availability | Alt 1 High |
| Future | (2) Mirage Flats canal recharge | High water availability | Alt 2 High |

## C. Economic Methodology

Agricultural and recreation benefits have been estimated independently under the conditions specified for each of the 10 alternatives/scenarios defined in table 3. The sum of agricultural and recreation benefits under a given alternative/scenario yielded the *combined benefits*. The costs associated with each alternative/ scenario were then subtracted from *combined benefits* to yield *net benefits* under each alternative/scenario. The results are presented in Appendix G and summarized below, in section VI-C.

The benefit-cost analysis (BCA) was conducted as six net benefits comparisons calculating the difference between each Action alternative/scenario and its No Action variant. Three additional net benefits comparisons are made solely for evaluating the economic effects of the three future climate change scenarios. In this case, the BLNA *without* climate change is compared to the FNA *with* climate change under each of the three climatic scenarios. These comparisons are technically not part of the BCA because no costs can be assigned to the climate scenarios — they will happen, or not, without any expenditure of funds to bring them about.

## 1. Agricultural Benefits Analysis

Agricultural benefits are based solely on the irrigated land falling within the boundaries of the MFID and the results have not been extrapolated to total Basin irrigated acreage. Assumptions and modeling details concerning the agricultural benefits portion of this analysis are described in Appendix G, section 2.1.

For the purpose of this analysis, *agricultural benefits* under a defined alternative/ scenario are estimated as *irrigation benefits* accrued to the agricultural district under the hydrologic conditions specified by that alternative/scenario. *Irrigation benefits* are measured as the change in net farm income received from the use of irrigation water to produce agricultural commodities (Reclamation, 2004a).

## 2. Recreation Benefits Analysis

Recreation benefits are based on reservoir recreation models developed for Box Butte and Merritt Reservoirs and a River Recreation Model developed for the most heavily used stretch of the designated Niobrara National Scenic River. To estimate recreation economic benefits under each alternative/scenario for the River and the two reservoir settings, analytical results were developed in terms of annual visitation and value per visit.

As discussed in Appendix G, section 2.2, average annual visitation estimates were developed based on hydrology and climate change projections specific to each alternative/scenario, but the value per visit is not alternative/scenario specific. Multiplying the average annual visitation estimates for each alternative/scenario times the values per visit for both the River and reservoirs resulted in estimates of average annual recreation economic value. Discounting and summing the range of annual values estimated across each year of the 50-year period of analysis results in a present value by alternative/scenario for use in the BCA.

## 3. Analysis of Costs

The only costs included in this economic analysis are those associated with construction activities. Annual operation, maintenance, replacement, and power (OMR&P) costs likely vary by alternative, but are beyond the scope of this analysis. The only scenarios that have a construction-related cost are those based on Alternative 1, the proposed Mirage Flats Pumping Station (Future Action (FA) 1-Low, FA1-CT, and FA1-High). These scenarios include the estimated $4.46 million cost of constructing a new pumping plant.

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# VII. Evaluation of Alternatives

## A. Ability to Deliver Water

### 1. Groundwater Model Results

The groundwater modeling results show that management operations will affect the baseflow and groundwater levels at least in the Upper Basin. Under the Baseline climate conditions, the baseflow under the two alternative management scenarios is generally lower between Dunlap and Gordon gages but higher between Box Butte Reservoir and the Dunlap gage than it is under the No Action management scenario (figure 10). Operational changes in the Mirage Flats area were found to have negligible effects on the baseflow downstream of the Gordon gage, so no comparative numbers are presented here for the Lower Basin baseflows under the two management alternatives.

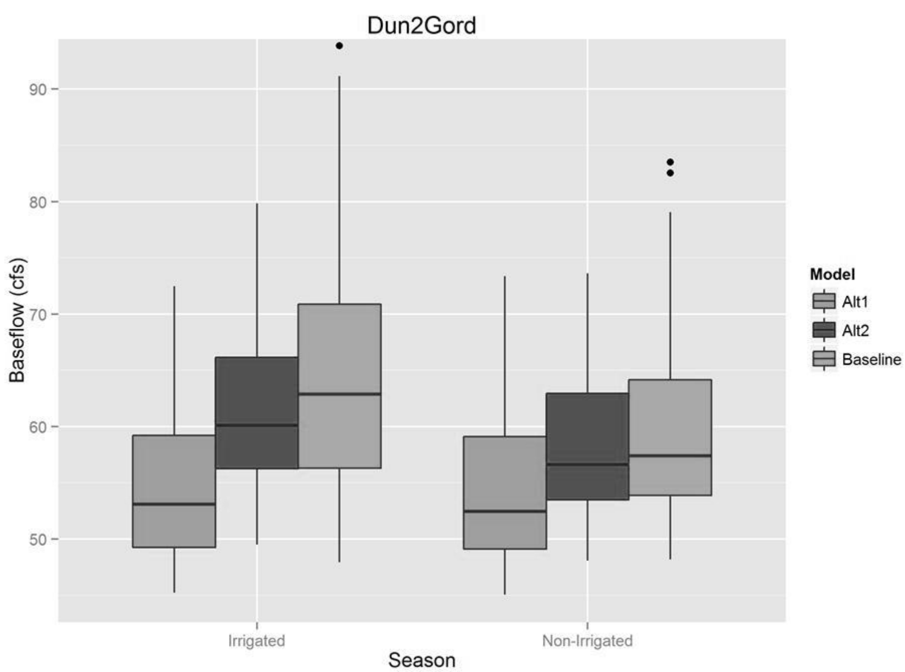


**Figure 10.—Box plot of baseflow between Dunlap and Gordon gages under Baseline, Alternative 1, and Alternative 2 Management Alternatives.**

The purpose of Operational Alternative 1 is to increase the efficiency of irrigation systems in the Mirage Flats area by installing a pumping station downstream and eliminating seepage from present canals to the groundwater system. However, the seepage losses in the canal are a significant source of localized recharge, which would be eliminated under Alternative 1. In the Alternative 1 model run,

the reduction in seepage losses (which contribute to the baseflow of the aquifer system) exceeds the sum of the increase in recharge (direct and indirect recharge) and the reductions in groundwater pumping. Therefore, the baseflow of the Alternative 1 run is lower than that of the Baseline run. In Alternative 2, canals and laterals in the MFID are intentionally used for groundwater recharge rather than for crop irrigation. The cumulative effect of the increase in recharge (direct and indirect) and the increase in groundwater pumping for crop irrigation leads to a decrease in the baseflow of the Alternative 2 run as compared to that of the Baseline. These changes in stream reach baseflow due to the alternatives affect only the Mirage Flats area, not the overall Basin.

The two management alternatives would also lead to some change in groundwater levels in the Mirage Flats area. Levels beneath the currently irrigated cropland would generally rise under both alternatives — as much as 11 feet under alternative 1 and 50 feet under alternative 2. In alternative 1, however, groundwater levels would fall several feet in the area west of a new pumping plant, adjacent to the main canal, which would be abandoned under this alternative. See figure B-8 (Appendix B) for a graphical representation of these changes.

## 2. Watershed Model Results

The primary purpose of the Watershed Model was to ensure water supplies and water uses were accounted for within a balanced water budget, while incorporating the climate data developed for this Basin Study. Alternative 1 (Mirage Flats Pumping Plant) was shown to be able to achieve its objective of improving the transportation efficiency of the surface water supplies within the MFID: under all climatic scenarios, this alternative would increase the volume of surface water delivered to irrigators and reduce the need for supplemental groundwater pumping. (See Appendix E, table E-29 and figures E-152through E-155.) This increased efficiency is realized by moving MFID's diversion point approximately 9 miles downstream and bypassing the relatively inefficient portion of the canal. However, the increase in efficiency of surface water deliveries would reduce the volume of canal seepage (Appendix E, figure E-172), which represents a significant source of localized recharge. The results summarized in Appendix E provide some helpful information should this alternative be considered in the future, but additional analyses of these results would be required to determine the tradeoffs between increased surface-water deliveries and reduced recharge from canal seepage.

Under Alternative 2 (Mirage Flats Canal Recharge), surface water deliveries in MFID would be eliminated and effectively change MFID into a groundwater-only district. Alternative 2 would create a relatively stable supply of groundwater recharge, generally at a rate greater than that of the No Action Alternative (Appendix E, figure E-199). The increase in recharge from the canal seepage would exceed any decrease in recharge resulting from changing the farm

irrigation practice. This water management strategy improves the timing of irrigation water by eliminating the dependency on surface water supplies and canal management practices. Providing a timely and sufficient volume of water to the crop is paramount to maximizing the benefit of the water. This alternative would be worth considering in any future evaluation of water management alternatives for MFID.

## 3. Integrated Model Results

### *a. Box Butte Reservoir Elevations*

Alternatives 1 and 2 maintain higher surface elevations in Box Butte Reservoir than the No Action Alternative (figure 11). Alternative 1 levels are higher because the increased canal efficiency allowing a lower volume of releases. Alternative 2 reservoir levels are higher because releases for irrigation would be much lower. Significant droughts equivalent to those of the mid-1970's and late-2000's would create decreases in Alternative 1 elevations, even with the increased canal efficiencies. As shown in table 4, both alternatives would have higher average daily elevations under the CT scenario over the course of the modeled 50 year period. The data is divided into annual and seasonal values (irrigation and non-irrigation season).

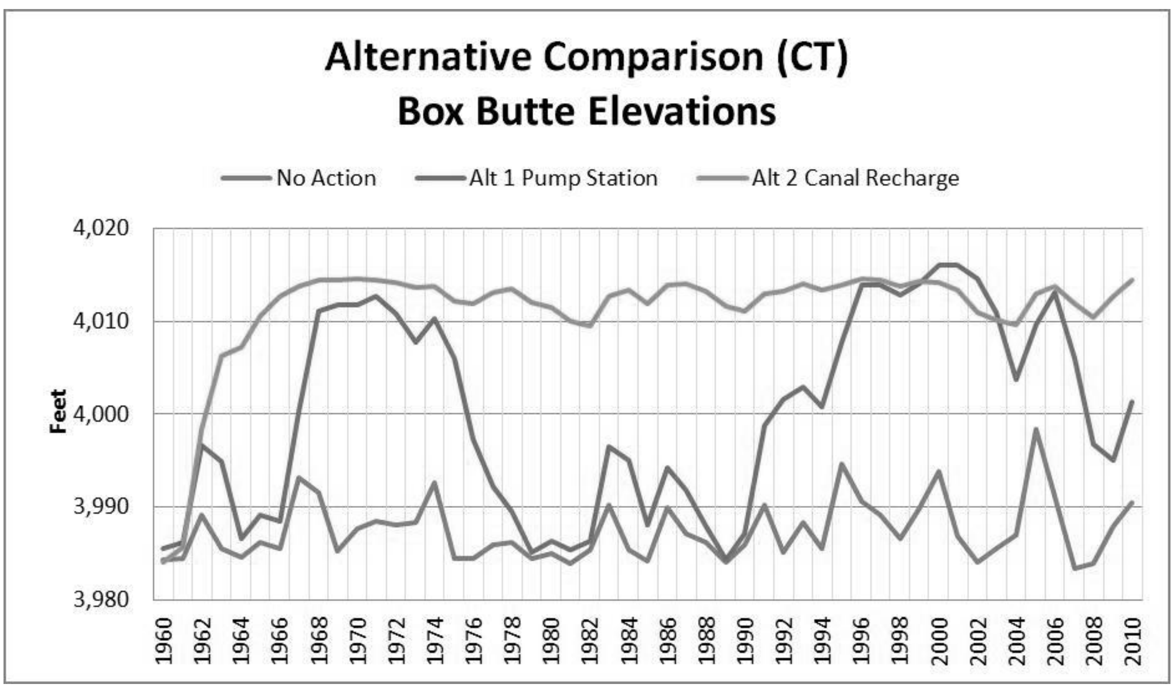


**Figure 11.—Average annual Box Butte Reservoir elevations under the CT scenario and the modeled operational alternatives for the Integrated Model.**

**Table 4.—Annual and Seasonal Average Box Butte Reservoir Elevations, in feet, under the CT Scenario and the Modeled Operational Alternatives under the Integrated Model**

| Alternative | Annual | Irrigation Season[1] | Non-Irrigation Season[1] |
|---|---|---|---|
| No Action | 3987.5 | 3983.5 | 3988.8 |
| Alt 1 Pumping Station | 4000.1 | 3999.3 | 4000.4 |
| Alt 2 Canal Recharge | 4011.2 | 4010.7 | 4011.4 |

[1] The irrigation season for the No Action Alternative and Alternative 1 was July, August, and September. The diversion pattern for Alternative 2 extended outside of the typical diversion season of the Mirage Flats area that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

### b. Mirage Flats Diversions

Under the Integrated Model CT climate scenario, MFIDs total annual diversions are lower under both action alternatives than under the No Action Alternative. Alternative 1 diversions are lower because of the increased canal efficiencies resulting in a lower volume of diversions to meet irrigation demands. Alternative 2 diversions were established to meet recharge demand. MFIDs total annual diversions for all the alternatives, under the CT climate scenario, are plotted in figure 12. Major differences are seen between the alternatives in the quantity of diversions. Overall, annual diversions to meet recharge demand under Alternative 2 are approximately 14 percent less than diversions required under Alternative 1 to meet MFID irrigation demands. Modeling of the diversions assumed that the canal has a 40-percent efficiency under the No Action Alternative and a 98-percent efficiency under Alternative 1. Figure 12 shows the decreases in amount of diversions for that alternative.

Modeling of Alternative 2 assumed there would be no deliveries and used a constant diversion rate for June, July, August, and September for every year of the simulation. The flat line in figure 12 shows an adequate supply to meet recharge demand. Table 5 summarizes the annual and seasonal daily average flows under the CT scenario over the course of the modeled 50-year period.

### c. Surface Water Irrigation Deliveries

Under the Integrated Model, the operational alternatives would affect surface water deliveries only within the MFID. Under all scenarios, the proposed pumping station increased surface water deliveries. Figure 13 compares the irrigation demand in the MFID to the average annual surface water deliveries under the No Action, pumping station, and canal recharge alternatives. Because the canal recharge alternative would use the existing network of canals only for recharging groundwater, surface-water deliveries under this alternative would be zero.

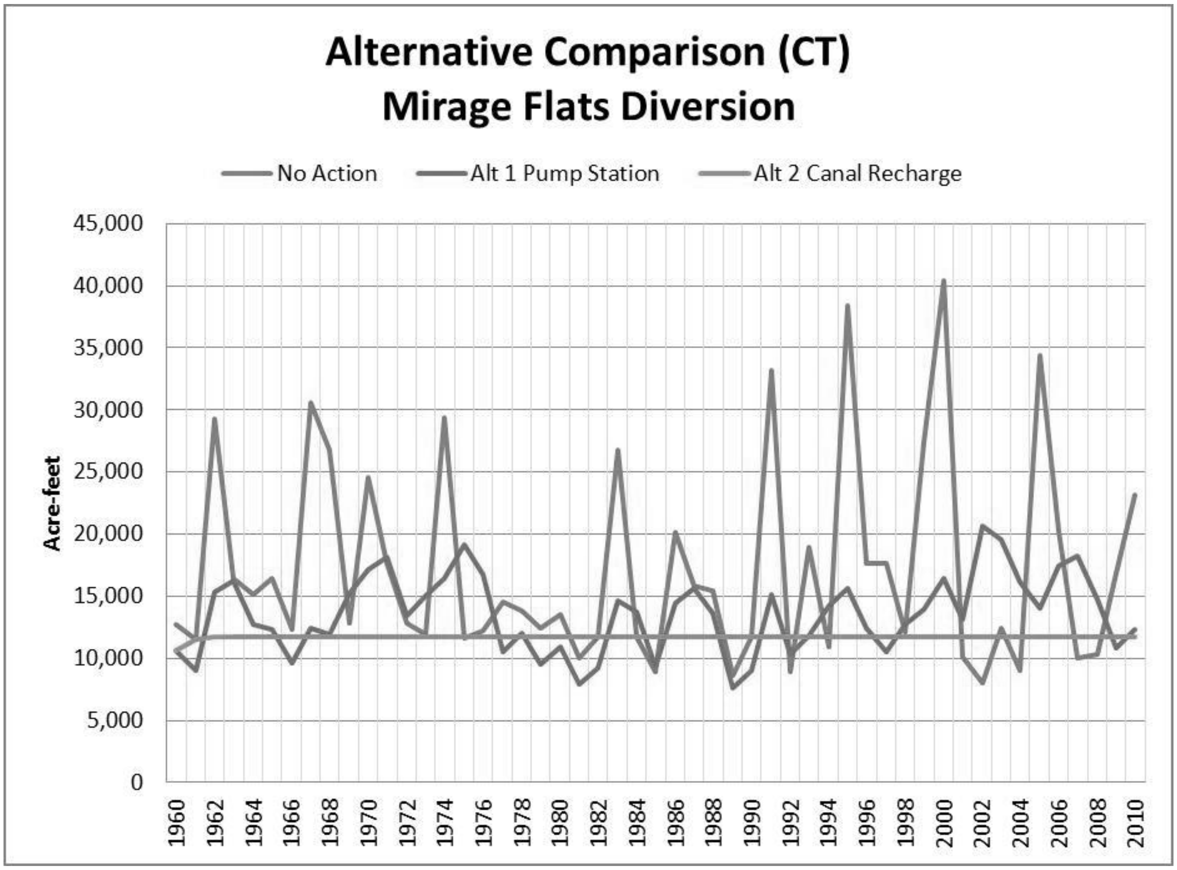


**Figure 12.—Total annual Mirage Flats diversion under the CT scenario and the modeled operational alternatives.**

**Table 5.—Mirage Flats Annual and Seasonal Daily Average Diversion, in Acre-Feet, under the CT Scenario and the Modeled Operational Alternatives**

| Alternative | Annual | Annual % of Baseline | Irrigation Season[1] | Non-Irrigation Season[1] |
|---|---|---|---|---|
| No Action | 47.2 | | 187.5 | 0.0 |
| Alt 1 Pumping Station | 37.1 | 79% | 147.1 | 0.0 |
| Alt 2 Canal Recharge | 32.1 | 68% | 79.0 | 16.3 |

[1] The irrigation season for the No Action Alternative and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of the Mirage Flats area that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

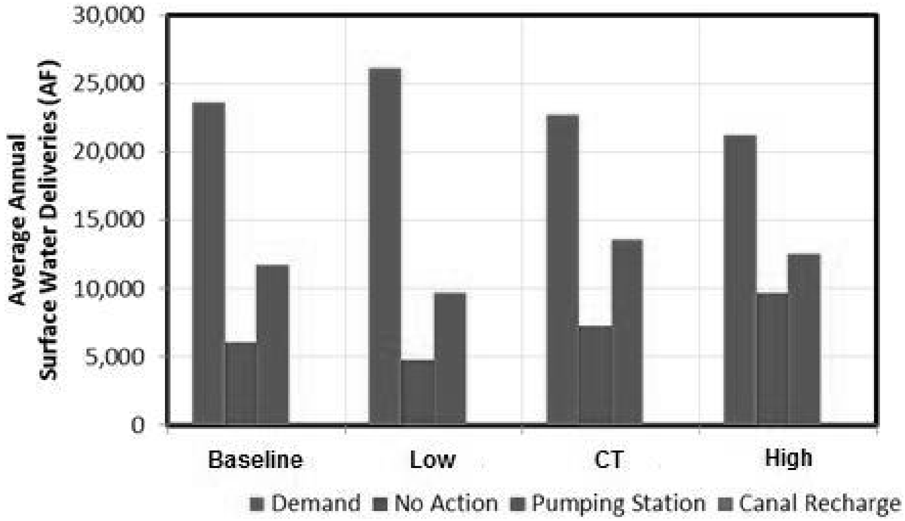


**Figure 13.—Mirage Flats average annual surface water demand versus deliveries under the modeled operational alternatives. Deliveries under Alternative 2 (Canal Recharge) are zero.**

### *d. Volume of Supplemental Groundwater Pumping on Surface-Water Irrigated Acres*

"Supplemental pumping" here refers to groundwater that irrigators have to pump when the supply of surface irrigation water is not sufficient for crop growth.

Under the Integrated Model, the operational alternatives affected supplemental pumping only within the MFID. Under all scenarios, the average volume of supplemental pumping decreased under the pumping station alternative and increased under the canal recharge alternative. Figure 14 compares the average annual supplemental pumping in the MFID under the no action, pumping station, and canal recharge alternatives.

### *e. Niobrara River at Gordon Gage*

Total annual flows on the Niobrara River at Gordon gage are very similar for all the alternatives under both the Low and CT climate scenarios (table 6). The similarity essentially shows that Box Butte Reservoir is an adequate buffer and can hold most of the surplus water generated by the lower demands under both operational alternatives. The reservoir is a less effective buffer under the High scenario, but even in that case the increase in flow is held to about 10 percent.

## B. Hydroelectric Power Generation

Spencer Hydropower Plant is the only hydropower facility in the Basin and a senior water-rights holder. A shortage of seasonal water supplies in recent years has led to the enforcement of the hydropower facility's water rights in the Basin. This has resulted in halting irrigation deliveries to upstream junior surface water appropriators on days that streamflow is insufficient to satisfy the senior rights.

Current and future water availability at this facility is most directly represented by measured and projected flows at the Spencer gage, which is located a short distance upstream of the Spencer Hydropower Dam. The mean annual flows at Spencer would increase an average of 15 percent above Baseline under the CT scenario. For the Low scenario, the mean annual flows would decrease an average of 8 percent, whereas they would increase an average of 34 percent under the High scenario. Figure 15 shows Baseline flows at the dam from 1960 through 2010 compared to projected flows under the Low, CT, and High climate scenarios over a similar 50-year period.

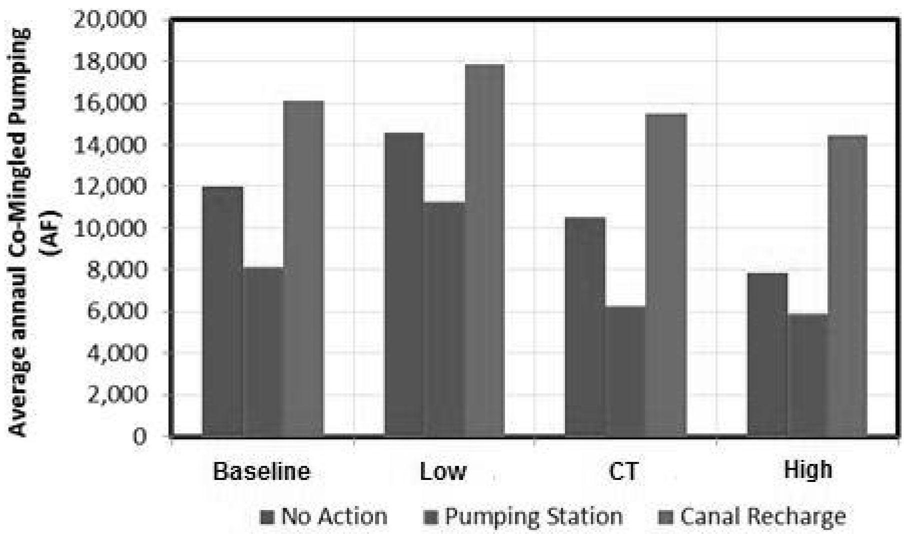


**Figure 14.—MFIDs average annual supplemental pumping under the modeled operational alternatives.**

**Table 6.—Gordon Gage Average Flow, in Acre-Feet per Day (AFD), under the Three Climatic Scenarios and the Modeled Operational Alternatives**

| Alternative | Low Scenario | | CT Scenario | | High Scenario | |
|---|---|---|---|---|---|---|
| | AFD | % of Baseline | AFD | % of Baseline | AFD | % of Baseline |
| No Action | 138 | | 199 | | 265 | |
| Alt 1 Pumping Station | 143 | 104% | 208 | 105% | 292 | 110% |
| Alt 2 Canal Recharge | 136 | 99% | 209 | 105% | 293 | 111% |

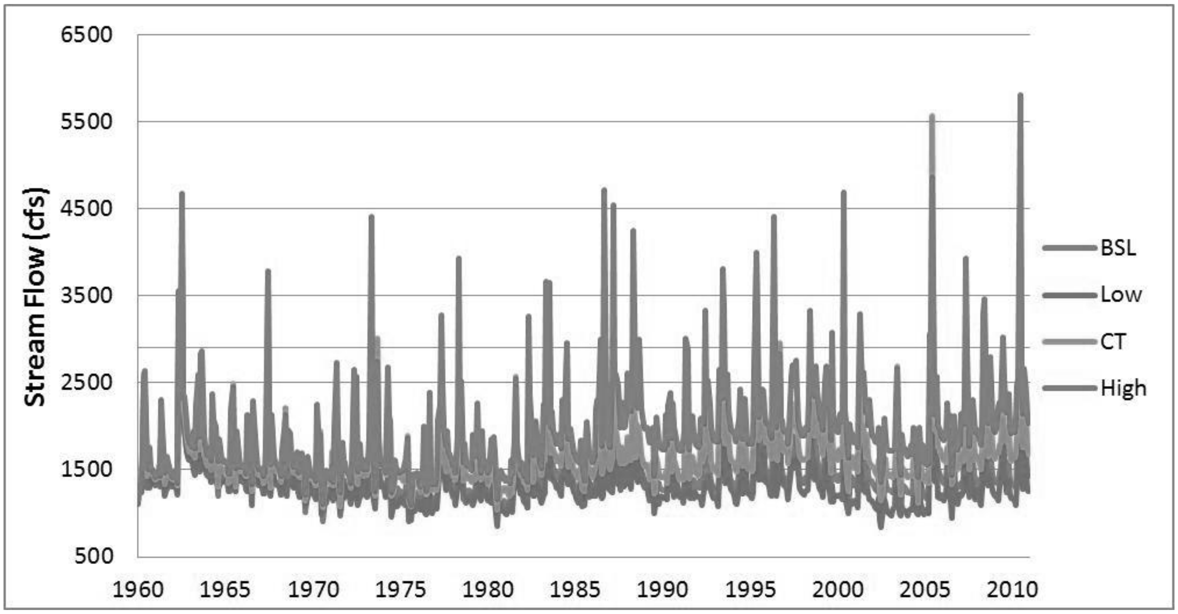


**Figure 15.—Monthly streamflows on Niobrara River near Spencer, Nebraska.**

## C. Agricultural and Recreation Benefits

Both agricultural and recreation benefits were initially estimated as annual values. The present value of the River's annual benefits under each alternative/scenario was then calculated using a 50-year planning horizon and the fiscal year (FY) 2015 Federal discount rate of 3.375 percent (Reclamation, 2014). The results (reported in table 7) show that either operational alternative would yield appreciably more benefits than the No Action Alternative under either the CT or the High climate scenario. Under the Low scenario, net benefits do not differ greatly between the alternatives, although they are slightly higher for Alternative 2 and slightly lower for Alternative 1, compared to the No Action Alternative. The net benefits are dominated by the recreational benefits, which increase under each FNA Alternative climate change scenario, due to increased temperatures under all three scenarios and increased water elevations under the CT and High scenarios.

The results imply that either of the action alternatives would be economically beneficial. Alternative 2 (canal recharge), however, provides the greatest estimated benefits under all three future climate scenarios.

**Table 7.—Present Value of Net Benefits under Defined Alternatives and Scenarios for Agricultural and Recreation Benefits**

All costs and benefits reported in millions of dollars

| Alternative/ Scenario | Agricultural Benefits[a] | Recreation Benefits[a] | Combined Benefits[a,b] | Costs[c] | Net Benefits[a,d] |
|---|---|---|---|---|---|
| Baseline No Action | $15.8 | $112.5 | $128.3 | $0.0 | $128.3 |
| Low No Action | $15.1 | $136.0 | $151.1 | $0.0 | $151.1 |
| Alt 1 Low | $17.3 | $137.0 | $154.3 | $4.5 | $149.8 |
| Alt 2 Low | $13.1 | $139.0 | $152.1 | $0.0 | $152.1 |
| CT No Action | $16.5 | $137.2 | $153.7 | $0.0 | $153.7 |
| Alt 1 CT | $18.5 | $146.3 | $164.8 | $4.5 | $160.3 |
| Alt 2 CT | $13.6 | $154.3 | $167.9 | $0.0 | $167.9 |
| High No Action | $17.5 | $133.7 | $151.2 | $0.0 | $151.2 |
| Alt 1 High | $18.3 | $141.3 | $159.6 | $4.5 | $155.1 |
| Alt 2 High | $13.9 | $147.7 | $161.6 | $0.0 | $161.6 |

a 50-year stream of benefits discounted at the FY2015 Federal discount rate of 3.375% (Reclamation, 2014).
b The sum of agricultural benefits and recreation benefits.
c Costs are only associated with any Future Alternative/Scenario that includes the Mirage Flats Pumping Station operational modification—see section 3 of Appendix F.
d Combined benefits minus costs.

## D. Fish and Wildlife Benefits

While all ecosystems in Nebraska will be affected by climate change, aquatic ecosystems (wetlands, lakes, streams, and rivers) may be the most highly impacted (University of Nebraska-Lincoln, 2014). Climate changes will alter both water quality and quantity. Increases in the frequency and intensity of high precipitation events, particularly in a landscape dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower stream flows and an increase in the frequency of stream segments being de-watered and wetlands drying up. Finally, increases in air temperature will result in increases in water temperature, causing a reduction in suitable habitat for cold-water dependent species, such as trout.

Dunnell and Travers (2011) report that some spring flowering species have advanced their first flowering time, some fall species have delayed their first flowering, and some species have not changed. Given the importance of flowering timing for reproductive success, the changing climate in the Great Plains is expected to have long-term ecological and evolutionary consequences for native plant species.

Available information on patterns of spatial climate variability and subregions of importance to ecological processes within the Great Plains was summarized by

Covich, et al., (1997). Climate sensitive areas of the Great Plains range from cold water systems (springs and spring-fed streams) to warmer, temporary systems (intermittent streams, ponds, shallow wetlands, playas).

Warmer water temperatures also could exacerbate invasive species issues (e.g., quagga mussel reproduction cycles responding favorably to warmer water temperatures); moreover, climate changes could decrease the effectiveness of chemical or biological agents used to control invasive species (Hellman et al., 2008). Warmer water temperatures also could spur the growth of algae, which could result in eutrophic conditions in lakes, declines in water quality (Lettenmaier et al., 2008), and changes in species composition. In addition, continued development in the northern Great Plains for energy extraction and other purposes has fragmented much of the landscape. This means that species facing declining habitat quality in their present locations due to climate change (changing habitat composition, timing of plant cycles, etc.) may find themselves surrounded by physical barriers and/or areas of completely unsuitable habitat that prevent them from migrating to more compatible territories (Shafer et al., 2014). The magnitude of expected changes will exceed those experienced in the last century. Current adaptation and planning efforts may need to be revised and expanded to respond to these projected impacts (Shafer, et al., 2014).

## E. Threatened and Endangered Species

In-depth analysis of the effects of climate change on species protected under the Federal Endangered Species Act (ESA) was determined to be a large undertaking that was outside the scope of this Basin Study. According to the USFWS, 14 species that may occur within the Basin Study area are currently protected under ESA. Two ESA candidate species may also be present in the study area. The Flatwater Group conducted a literature review (Literature Review of Habitat Position, Threats, and Climate Change Vulnerability for Federally Listed Species) to summarize existing information for these 16 species. This included an online search for each species to determine its habitat position within the Basin, and then the species were grouped into aquatic habitat, terrestrial/ aquatic habitat, and terrestrial habitat groups. For each of these species, all identified threats and the species' vulnerability to climate change are listed in table 8.

According to this literature analysis, these 16 species are expected to exhibit varying responses to the effects of climate change. Four plant species — the Colorado butterfly plant, Topeka shiner, Ute ladies'-tresses, and Western prairie fringed orchid — are regarded to be extremely vulnerable to the effects of climate change. According to Young, et al., (2015), this means these species are "extremely likely" to experience a substantial decrease in their abundance and/or distribution within the study area by 2050. Two more species — the American burying beetle and the blowout penstemon plants — are classified as highly vulnerable to the effects of climate change, and are likely to experience

significant decreases in distribution and/or abundance within the area by 2050 (Young et al., 2015).

**Table 8.—Literature Review of Habitat Position, Threats, and Climate Change Vulnerability for Federally Listed Species within the Niobrara River Basin**

| Habitat Group[1] | Species | Habitat[2] | ESA Status[3,4] | Species Range[4] | | | Threats[2] | Climate Change Vulnerability Index[5] |
|---|---|---|---|---|---|---|---|---|
| | | | | NE | SD | WY | | |
| AQUATIC | Pallid sturgeon (*Scaphirhynchus albus*) | Large turbid rivers, steep drop-offs at the edge of sandbars, sandy areas, downstream end of islands | E | X | X | X | Manipulation of water flow, sediment transport, channelization, lack of low flow, habitat fragmentation, loss of spawning habitat, illegal commercial harvest, current manipulation of hydrology | Not vulnerable, presumed stable |
| AQUATIC | Topeka shiner (*Notropis topeka*) | Cold/cool clear water streams with gravel, low gradient | E | X | | | Sedimentation, exotics, channelization, stocking of sport fish, row crop agriculture, flow modification, dewatering dams, loss of off-channel quiet-water habitats, degradation of riparian areas | Extremely vulnerable |
| AQUATIC / TERRESTRIAL | Least tern (*Sterna antillarum*) | Bare sand bars and sandy shorelines of large rivers, lakes and sand pits, housing developments | E | X | X | X | Loss of dynamic river flows to form and maintain bare macro-form sandbar and shoreline habitat, flooding of nests, loss of nests to vehicles and human disturbance, hydro-peaking, invasive plant species affecting nesting habitat | Not vulnerable, Presumed stable |
| AQUATIC / TERRESTRIAL | Piping plover (*Charadrius melodus*) | Bare sand bars and sandy shorelines of large rivers, lakes and sand pits | T | X | X | X | Loss of dynamic river flows to form and maintain bare macro-form sandbar and shoreline habitat, flooding of nests (hydro-peaking), loss of nests to vehicles and human disturbance, invasive plant species affecting nesting habitat, loss of over-wintering habitat along the Gulf | Not vulnerable, presumed stable |
| AQUATIC / TERRESTRIAL | Red knot (*Calidris canutus rufa*) | Sandy beaches.[6] | T | | X | | Loss of habitat across range due to sea-level rise, increased predation.[6] | Data Not Available |
| AQUATIC / TERRESTRIAL | Whooping crane (*Grus Americana*) | Wetlands, wet meadows, sandbars and shallow water in rivers; spring and fall migrant, does not nest in Nebraska | E | X | X | X | Loss of natural river flows to maintain wet meadows, bare sandbar and shallow water habitat, loss of wetland habitat, wind energy development, tree encroachment in wet meadows | Not vulnerable, Presumed stable |
| TERRESTRIAL | American burying beetle (*Nicrophorus americanus*) | Wet meadows in sandhills, open woodlands, loess canyons | E | X | X | | Woody encroachment, drought, land development, light pollution | Highly vulnerable |
| TERRESTRIAL | Black-footed ferret (*Mustela nigripes*) | Prairie dog colonies found in short and mid-grass prairies of the Great Plains | E | X | X | | Predators and disease | Data Not Available |
| TERRESTRIAL | Blowout penstemon (*Penstemon haydenii*) | Sandhills dune prairie (blowouts) | E | X | | X | Loss of blowouts because of present range management practices, lack of fire, recent climatic conditions | Highly vulnerable |

| Habitat Group[1] | Species | Habitat[2] | ESA Status[3,4] | Species Range[4] | | | Threats[2] | Climate Change Vulnerability Index[5] |
|---|---|---|---|---|---|---|---|---|
| | | | | NE | SD | WY | | |
| TERRESTRIAL | Colorado butterfly plant (*Gaura neomexicana var. coloradensis*) | Western floodplain terrace grassland | T | | | X | Canada thistle invasion of habitat, herbicide spraying, groundwater level decline, haying and heavy grazing of habitat | Extremely vulnerable |
| | Greater sage-grouse (*Centrocercus urophasianus*) | Sagebrush country.[7] | C | | | X | Loss and fragmentation of sagebrush, agricultural conversion, infrastructure, invasive plants, fire cycle.[7] | Data Not Available |
| | Northern long-eared bat (*Myotis septentrionalis*) | Caves and mines (winter) and underneath tree bark, and cavities or crevices of dead trees (summer).[8] | PE | | X | | Cave entrance gates, development, wind farm operation.[8] | Data Not Available |
| | Preble's meadow jumping mouse (*Zapus hudsonius preblei*) | Well-developed plains riparian vegetation with adjacent undisturbed grassland communities and nearby water source.[9] | T | | | X | Habitat loss and predators.[9] | Data Not Available |
| | Sprague's pipit (*Anthus spragueii*) | Short to tall-grass prairies, grazed to 5–15 cm, pastures, harvested fields (alfalfa or wheat stubble); spring and fall migrant; does not nest in Nebraska | C | | X | | Undetermined, loss of breeding habitat, but unclear if there are threats during migration | Not vulnerable, Increase likely |
| | Ute ladies'-tresses (*Spiranthes diluvialis*) | Western alkaline meadow | T | X | | X | Reduced groundwater levels, invasive species, conversion of meadows to cropland, annual haying of meadows | Extremely vulnerable |
| | Western prairie fringed orchid (*Platanthera praeclara*) | Eastern cordgrass wet prairie, northern cordgrass wet prairie, wet-mesic tallgrass prairie, tallgrass prairie | T | X | X | X | Invasive species, herbicide spraying, conversion of prairie to cropland and development, annual mid-summer haying, inappropriate grazing | Extremely vulnerable |

[1] Generalized groupings for this table based on geomorphic location of habitat.
[2] Source of information *unless otherwise specified*: Appendix 8 of Nebraska Natural Legacy Projecthttp://outdoornebraska.ne.gov/wildlife/programs/legacy/Natural_legacy_document.asp
[3] E=Endangered, T=Threatened, C=Candidate
[4] Source: USFWS Information for Planning and Conservation (IPAC) Tool, http://ecos.fws.gov/ipac/http://ecos.fws.gov/ipac/, accessed 6/1/2015
[5] Climate change vulnerability assessments were conducted using NatureServe's Climate Change Vulnerability Index tool (Young, et al., 2011). The tool is designed to be used for a specific geographic area, which in this case was the State of Nebraska. Therefore the Index score may be incomplete for migratory bird species that spend part of the year outside of Nebraska.
[6] Source: http://www.fws.gov/northeast/redknot/pdf/DRAFT_QAs_red_knot_finallisting_120814_FINAL.pdf
[7] Source: http://www.fws.gov/greatersagegrouse/factsheets/GreaterSageGrouseCanon_FINAL.pdf
[8] Source: http://www.fws.gov/midwest/endangered/mammals/nlba/nlbaFactSheet.html
[9] Source: http://www.fws.gov/mountain-prairie/species/mammals/preble/Note: NE Nebraska, SD South, Dakota, WY Wyoming

The results of the literature review illustrate the serious threat climate change poses for a number of ESA-listed species that may occur within the Basin Study area. Climate information provided in this Study Report should be useful to researchers addressing the effects of climate change on ESA-listed species that occur within the Basin.

## F. Species of Special Conservation Concern

In addition to the species protected under the Federal ESA, the States of Nebraska, South Dakota, and Wyoming have identified a number of species of special conservation concern that may occur within the Basin. Table 9 provides a list of these species and their status for each State. Species listed under the Nebraska Nongame and Endangered Species Conservation Act or the South Dakota State Endangered Species Law may be designated as threatened (ST) or endangered (SE). Wyoming species may be designated as Species of Greatest Conservation Need (SGCN) in accordance with the Wyoming State Wildlife Action Plan. Species listed as SGCN in Wyoming are assigned a ranking of NSS1 (extremely imperiled), NSS2 (severely imperiled or extremely vulnerable), NSS3 (severely vulnerable), NSS4 (moderately vulnerable or stable with severe limiting factors), or NSSU (status unknown, additional information needed) under the Wyoming Native Species Status (NSS) classification system (WGFD, 2010). The numerous State-designated species in table 9 can be expected to exhibit varying responses to the effects of climate change. In-depth analysis of these responses was determined to be a large undertaking that was outside the scope of this Basin Study. However, the climate information provided here should be useful for researchers addressing the effects of climate change on these species.

## G. Flood Control

The authorized purposes of Merritt and Box Butte Reservoirs are to provide storage for irrigation, recreation, and fish and wildlife. Box Butte Reservoir also has the additional purpose of providing sediment control. Neither of these is operated as a flood control reservoir, and the operational changes considered here would probably have little effect on future flooding.

**Table 9.—State-Designated Species of Special Conservation Concern for this Basin Study Area**

| Common Name | Scientific Name | Nebraska Status | South Dakota Status | Wyoming Status |
|---|---|---|---|---|
| Bald eagle | Haliaeetus leucocephalus | | ST | SGCN (NSS2) |
| Bighorn sheep | *Ovis canadensis* | | | SGCN (NSS4) |
| Blacknose shiner | Notropis heterolepis | SE | SE | |
| Brewer's sparrow | *Spizella breweri* | | | SGCN (NSS4) |
| Burrowing owl | *Athene cunicularia* | | | SGCN (NSSU) |
| Chestnut-collared longspur | *Calcarius ornatus* | | | SGCN (NSS4) |
| Dickcissel | *Spiza americana* | | | SGCN (NSS4) |
| False map turtle | *Graptemys pseudogeographica* | | ST | |
| Ferruginous hawk | *Buteo regalis* | | | SGCN (NSSU) |
| Finescale dace | Chrosomus neogaeus/ Phoxinus neogaeus | ST | SE | |
| Grasshopper sparrow | *Ammodramus savannarum* | | | SGCN (NSS4) |
| Lake sturgeon | Acipenser fulvescens | ST | | |
| Lewis's woodpecker | *Melanerpes lewis* | | | SGCN (NSSU) |
| Little brown myotis | *Myotis lucifugus* | | | SGCN (NSS4) |
| Long-billed curlew | *Numenius americanus* | | | SGCN (NSS3) |
| Mccown's longspur | *Rhynchophanes mccownii* | | | SGCN (NSS4) |
| Merlin | *Falco columbarius* | | | SGCN (NSSU) |
| Northern goshawk | *Accipiter gentilis* | | | SGCN (NSSU) |
| Northern leopard frog | *Lithobates pipiens* | | | SGCN (NSSU) |
| Northern many-lined skink | *Plestiodon multivirgatus multivirgatus* | | | SGCN (NSSU) |
| Northern pearl dace | *Margariscus nachtriebi* | | ST | |
| Northern redbelly dace | Chrosomus eos/Phoxinus eos | ST | ST | |
| River otter | Lontra canadensis | ST | ST | |
| Sagebrush sparrow | *Artemisiospiza nevadensis* | | | SGCN (NSS4) |
| Sandhill crane | *Grus canadensis* | | | SGCN (NSS4) |
| Sicklefin chub | *Macrhybopsis meeki* | | ST | |
| Short-eared owl | *Asio flammeus* | | | SGCN (NSS4) |
| Small white lady's slipper | Cypripedium candidum | ST | | |
| Sturgeon chub | Macrhybopsis gelida | SE | ST | |
| Swift fox | Vulpes velox | SE | ST | SGCN (NSS4) |
| Virginia rail | Rallus limicola | | | SGCN (NSS3) |

[1] Source: http://outdoornebraska.ne.gov/wildlife/programs/nongame/Heritage/ET_Ranges.asp and email correspondence with Rachel Simpson, Data Manager, Nebraska Natural Heritage Program, Nebraska Game and Parks Commission (April 8, 2015)
[2] Source: http://gfp.sd.gov/wildlife/docs/ThreatenedCountyList.pdf
[3] Source: Email correspondence with Melanie Arnett, Database Specialist, Wyoming Natural Diversity Database, University of Wyoming (March 27, 2015)
Note: ST threatened or SE endangered; NSS1 extremely imperiled), NSS2 severely imperiled or extremely vulnerable, NSS3 severely vulnerable, NSS4 moderately vulnerable or stable with

severe limiting factors, or NSSU status unknown, additional information needed) under the Wyoming Native Species Status (NSS)

## H. Water Quality

Climate changes are anticipated to alter, not only the quantity, but also the quality of water in the Basin. Increases in the frequency and intensity of high precipitation events, particularly in an agriculture-dominated landscape, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies.

Water quality in the Basin is monitored by Nebraska, South Dakota, and Wyoming. According to the State of Wyoming, water quality in the Niobrara River headwaters has been difficult to monitor because the surface water resources consist primarily of springs and ephemeral or intermittent streams. The limited amount of data available for one headwater stream, Silver Springs Creek, indicates that its water quality is good, with no reported impairments (WDEQ, 2014).

Water quality in the South Dakota portion of the Basin Study area is monitored at one impoundment, Rahn Lake, and one Niobrara River tributary, the Keya Paha River. Rahn Lake is classified as impaired due to chlorophyll-a concentrations (SDDENR, 2014). Chlorophyll-a is an index of phytoplankton biomass; high chlorophyll-a levels may indicate nutrient enrichment (Carpenter et al., 1998; Hambrook Berkman and Canova 2007). No total maximum daily loads (TMDLs) have been developed for this impoundment. The water quality of the Keya Paha River is classified as threatened due to *Escherichia coli* (*E. coli*) and fecal coliform bacteria concentrations. The Keya Paha River has TMDLs in effect for both contaminants (SDDENR, 2014).

The State of Nebraska monitors water quality for 66 lakes and impoundments and 251 stream segments within thus Basin Study area. Ten of the 66 lakes/ impoundments are classified as impaired due to various known and unknown contaminants including nutrients (nitrogen and phosphorous) and hazard index compounds (various PCBs, pesticides, heavy metals, and other compounds). The two largest impoundments, Box Butte and Merritt Reservoirs, are both classified as impaired due to pH (both reservoirs), fish consumption advisories (both reservoirs), and total nitrogen and phosphorous concentrations (Merritt Reservoir only). No TMDLs have been developed for either reservoir (NDEQ, 2014).

Seventeen of the 251 Basin stream segments monitored by the State of Nebraska are classified as impaired due to known and unknown contaminants, including *E. coli* bacteria and hazard index compounds. The most common contaminant, *E. coli,* is reported for all 17 impaired segments (NDEQ, 2014). The State of Nebraska published *E. coli* TMDLs for all impaired stream segments of the Basin, including multiple segments of the Niobrara River, in 2005 (NDEQ, 2005).

Increases in runoff due to climate change would be expected to increase contaminant loads to surface waters. Increased contaminant loads could lead to

additional impaired water designations within the Basin, as well as continued impairment of waters currently classified as impaired. Figure 16 shows a visual representation of the stream segments and lakes/impoundments currently classified as impaired within the Basin Study area.

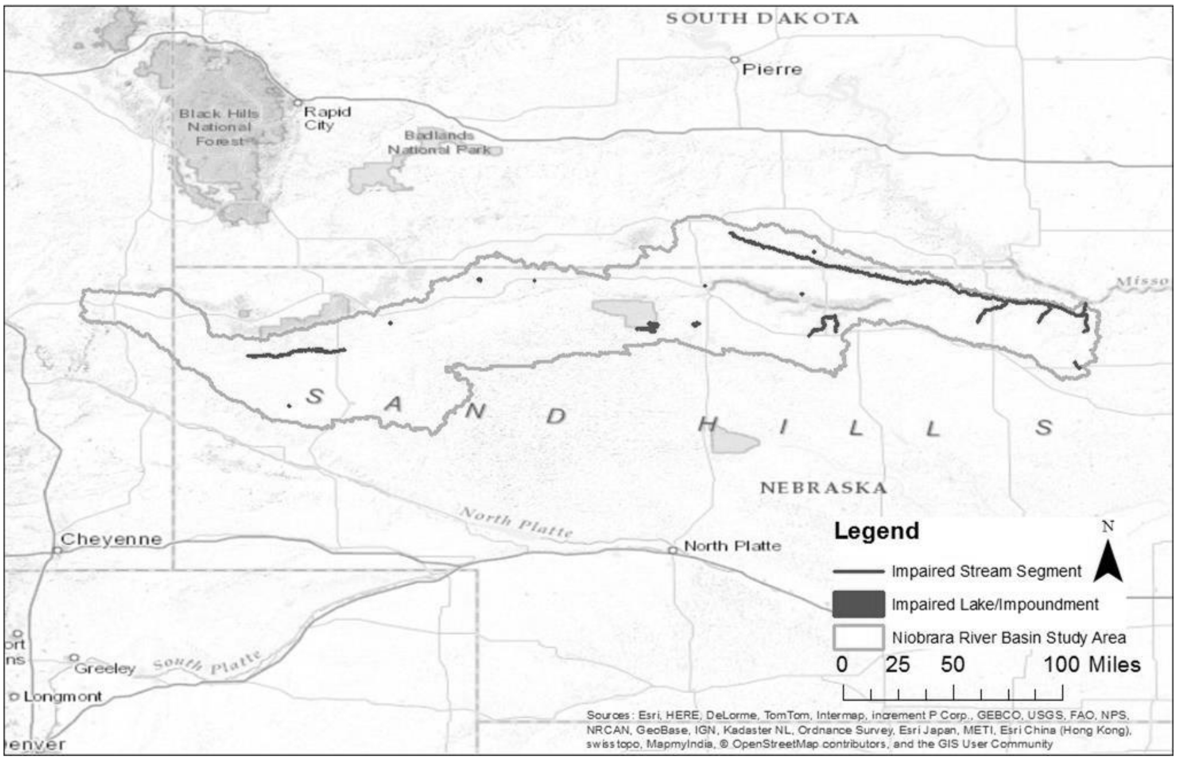


**Figure 16.—Impaired stream segments and lakes/impoundments within the Basin Study area.**

17-01174_012336;17-01174_012336;17-01174_012337;17-01174_012338;17-01174_012339;17-01174_012340;1...

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RECLAMATION

*Managing Water in the West*

RECLAMATION
*Managing Water in the West*

Technical Memorandum No. 86-68210–2015-04

# Niobrara River Basin Study
## Appendix A —
## Climate Change Analysis

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

February 2016

## Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

On cover: Aerial view of the Wild and Scenic portion of the Niobrara River. Photo by Michael Melford (http://www.michaelmelford.com/); used with permission.

**Technical Memorandum No. 86-68210–2015-04**

# Niobrara River Basin Study
## Appendix A —
## Climate Change Analysis

*Prepared by:*

**Technical Service Center**
**Water and Environmental Resources Division (86-68200)**
**Water Resources Planning and Operations Support Group (86-68210)**

**Marketa M. Elsner, PE, Hydrologic Engineer**

*Peer reviewed by:*
**Subhrendu Gangopadhyay, PE, PhD, Supervisory Hydrologic Engineer**

**U.S. Department of the Interior**
**Bureau of Reclamation**
**Technical Service Center**
**Denver, Colorado**

**February 2016**

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# Executive Summary

## Purpose, Scope and Objectives

The Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (DNR) and the Bureau of Reclamation (Reclamation), which is authorized under the SECURE Water Act (Title IX, Subtitle F of Public Law 111-11). The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region on identification and evaluation of potential adaptation strategies which may reduce any identified gaps. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessments ([WWCRA]; Reclamation, 2011; Reclamation, 2015) but contain additional information, if available.

The purpose of this report is to summarize the climate change analysis for the Basin Study and discuss development of climate related inputs for various modeling components of the Basin Study by Reclamation's Technical Service Center. The executive summary provides a general basin scale assessment of historical and future water supply. The following report provides additional details of the water supply assessment and also summarizes ways in which linkages between various Basin Study modeling components were developed to incorporate historical and projected climate and hydrologic information. Additional Basin Study technical reports supplement this analysis and contribute to the overall Basin Study report.

## Interrelated Activities — Federal WaterSMART Program

The federal Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program provides the underlying mechanism for initiating the Basin Study. The WaterSMART Program was established by the Secretary of Interior under Secretarial Order 3297 to address an increasing set of water supply challenges, including chronic water supply shortages due to increased population growth, climate variability and change, and heightened competition for finite water supplies. The WaterSMART Program was developed as means of implementing the SECURE Water Act of 2009 (Public Law 111-11). Through WaterSMART, Reclamation is making use of the best available science in the assessments it conducts and the policies it employs, with the goal of securing future water supplies.

## Summary of Previous and Current Studies

Climate in Nebraska, as well as in the Niobrara River Basin, is well known for its climate extremes and for having a substantial moisture gradient from west to east, with the western portion being semiarid and the eastern portion being more

humid. Annual precipitation totals for Nebraska range from 36 inches in the southeast to less than 15 inches in the northwest (University of Nebraska-Lincoln, 2014). As one example of its climate variability, an average of 40 percent of the annual precipitation typically falls from May through July, while only 5 to 7 percent of the annual total normally falls from December through February. In addition, the 1930s and 1950s saw widespread droughts, while the last 50 years have generally been wetter than average.

Nebraska has experienced an overall warming trend of about 1 degrees Fahrenheit (°F) since 1895. Seasonally, the trends show greater warming in winter (defined as December - February) and spring (defined as March - May), 2.0°F and 1.8°F, respectively. The length of the frost-free season in Nebraska has increased, anywhere from 5 to 25 days and on average by more than one week since 1895 (University of Nebraska-Lincoln, 2014). Although it is difficult to attribute historical precipitation variability to human induced change (Hoerling et al., 2010), there is growing evidence of a linkage between the warming of the globe, arctic sea ice decline and extreme winters across the GP Region (Reclamation, 2013).

Reclamation's WWCRA (Reclamation, 2011) indicates the Great Plains region will continue to experience the kind of interannual to interdecadal variations in precipitation that it has experienced historically. In addition, climate change will further exacerbate climate hazards such as tornadoes, droughts, floods and increase economic losses in the future (University of Nebraska-Lincoln, 2014). According to Nebraska's climate change impacts assessment (University of Nebraska-Lincoln, 2014), projected changes in temperature for Nebraska range from 4 - 5°F (low emission scenarios) to 8 - 9°F (high emission scenarios) by the late twenty-first century (2071-2099). Projected changes in temperature and precipitation are expected to coincide with a decreasing trend in spring snow water equivalent (SWE), a decreasing trend in April–July runoff volume, increasing trends in December–March and annual runoff volumes, and reduced soil moisture levels (Reclamation, 2013). However, it should be noted that uncertainties associated with the hydrologic analysis may impact results of climate change impacts studies (Vano et al., 2012).

Future climate and hydrologic projections in the Niobrara River Basin will impact various environmental resources pertinent to the Basin Study to varying degrees, including water resources, agriculture, aquatic ecosystems, invasive species, and other related resources. Irrigators may face allocation restrictions that set limits on the amount of water that can be applied on an annual basis. By the year 2100, the Third National Climate Assessment (Shafer et al., 2014) indicates that the frost-free season will increase by 30 to 40 days for Nebraska. The assessment also suggests that changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; and as these trends continue, they will require new agriculture and livestock management practices (Shafer et al., 2014).

Climate changes are anticipated to alter both water quality and quantity. Increases in the frequency and intensity of high precipitation events, particularly in a landscape such as the Niobrara River basin that is dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower stream flows and an increase in the frequency of stream segments being de-watered and wetlands drying up (University of Nebraska-Lincoln, 2014).

## Historical Surface Water Availability

The Variable Infiltration Capacity Model ([VIC], described in detail in Section 2.1) was employed over the historical period 1950-2010 to quantify historical trends in surface water availability. The VIC model is an advantageous tool for this type of evaluation since this model has been applied over the continental United States and beyond, and is the basis for assessments under Reclamation's WWCRA (Reclamation, 2011). The VIC model may be implemented at any spatial resolution, adhering to a latitude-longitude grid. For this Basin Study, and for consistency with Reclamation's WWCRA, the model was implemented over the study area at 1/8 degree, or approximately 12 kilometer resolution. VIC provides a wide array of hydrologic outputs, typically including runoff, snow-water equivalent and evapotranspiration (ET), which are routinely analyzed to assess climate change impacts on watershed hydrology.

Historical trend analysis over the period 1950-2010 indicates an increasing trend in mean annual temperature and precipitation during this period, along with increases in ET and runoff. Historical trends in precipitation and temperature computed using the Maurer et al. (2002) meteorological dataset, whose extended dataset through 2010 was used as input to the VIC model, are generally consistent with historical trends reported by the University of Nebraska-Lincoln (2014) study as well as by Reclamation's 2013 Literature Synthesis. Table ES-1 summarizes computed historical trends in mean annual precipitation, temperature and runoff.

**Table ES-1.—Summary of Historical Trends in Precipitation, Daily Average Temperature, and Annual Runoff, Computed from VIC Model Simulations Over 1950–2010**

| | Basinwide Change | Percent Change |
|---|---|---|
| Precipitation | + 2.2 in | + 12% |
| Daily Average Temperature | + 0.56 °F | -- |
| Annual Runoff | + 0.55 in | + 45% |

## Data and Models Used to Evaluate Climate Change Effects on Water Supply

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, as opposed to days or weeks. Arguably the most common approach for developing scenarios of future climate involves downscaling information (in space and time) from native scale Global Climate Model (GCM) resolution to a finer resolution suitable for long term planning studies such as the Basin Study.

Development of climate scenarios for the Basin Study relies on projections of future climate and hydrologic conditions developed under Reclamation's WWCRA (Reclamation, 2011). The Basin Study involves numerous modeling components which are brought together to evaluate watershed response to projected future climate conditions and to various water management alternatives. There is a need to adequately represent the projected range of future climate conditions, while also limiting the number of required simulations to maintain a manageable project scope. Therefore, three future climate change scenarios were developed as input to the hydrologic and management modeling framework to encompass range of projected water availability in the watershed, defined as mean annual difference between precipitation and ET, for the 2030-2059 future time horizon.

Climate change scenarios were developed based on individual climate projections selected directly from the 112 available CMIP3-based projections (further described in Section 3.1) to represent low projected water availability (hereafter called the Low scenario), median projected water availability (hereafter called the Central Tendency scenario), and high projected water availability (hereafter called the High scenario), as well as a range of projected change in summer temperature and precipitation. The selected Low scenario corresponds with a decrease in water availability by approximately -9 percent. The select Central Tendency scenario corresponds with an increase in water availability of approximately 6 percent. The select High scenario corresponds with an increase in water availability of approximately 37 percent.

Historical climate data is also used along with assumed current water demands (in this case set at 2010 levels) to establish a Baseline No Action scenario, to be used as a benchmark for evaluation of climate change impacts by the Basin Study integrated models. Future climate change scenario data (representing a future time horizon of 2030-2059) is used along with assumed current water demands (set at 2010 levels) to explore future water supply and demand under a range of future climates. These scenarios are termed Future No Action (Low, Central Tendency, and High). The Basin Study also explores two selected management alternatives under the same future change scenario data and assumed future demands. Generally, the first alternative includes changing the location of surface water diversion from the Niobrara River to the Mirage Flats Irrigation District to

reduce conveyance losses in the current canal system. The second alternative includes using existing canal systems to recharge the groundwater system during periods of excess available water. These alternative scenarios are termed Future with Alternative (Low, Central Tendency, and High). Together, the Future No Action scenarios may be used to evaluate how climate change might impact current water management. Further, the Future with Alternative scenarios may be used to evaluate how alternatives may reduce projected water supply/demand gaps identified by the Future No Action scenarios.

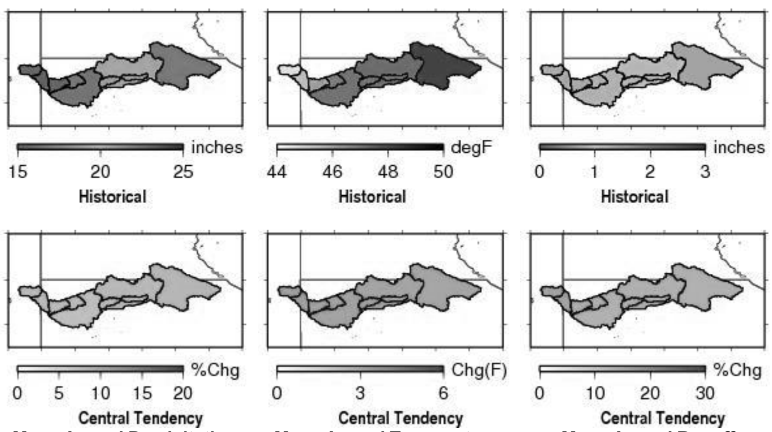
## Effects of Climate Variability and Change on Water Supply

Historical and projected changes in climate and water balance variables are summarized for each of the three climate change scenarios developed for the Basin Study. Specifically, the Low scenario represents projected low water availability and generally corresponds with hotter and drier future climate. The Central Tendency scenario represents the middle-of-the-road water availability and generally corresponds with the central tendency of all available GCM projections for the chosen future time horizon. The High scenario represents high projected water availability and generally corresponds with wetter and less warm future climate. Together, the climate change scenarios are intended to represent a range of projected future conditions.

The following figure (figure ES-1) summarizes historical and projected mean annual precipitation, temperature, and runoff averaged over select zones for the Central Tendency scenario and 2030-2059 future time horizon. The zones, which are illustrated in figure 9 Section 3.2.2 by colored polygons, correspond with the modeled runoff zones by the watershed model and groundwater models for the Upper Niobrara White (UNW) and Central Nebraska (CENEB) subregions. Zones represent major Niobrara River subbasins and correspond with the contributing drainage area to selected USGS gages. Projected changes basin wide for the Central Tendency scenario indicate an increase in mean annual precipitation by about 8 percent, an increase in mean annual temperature by about 3°F, and an increase in mean annual runoff by about 13 percent (refer to table 7 for additional details).

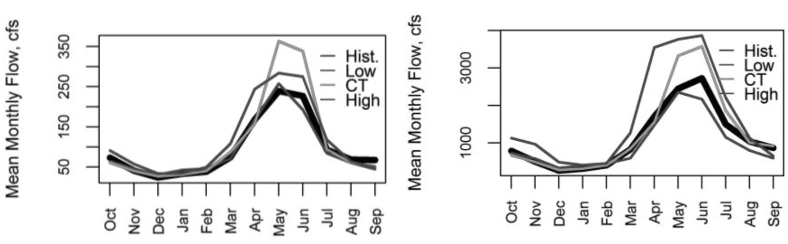
The VIC model, along with a separate streamflow routing routine, was used to develop historical and projected natural (unimpaired) streamflow for the chosen future time horizon at model nodes used throughout the Basin Study (refer to table 1 in Section 1.1.2). Historically, unimpaired streamflow in the basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Projected mean monthly unimpaired streamflow for the Central Tendency scenario indicates a substantial increase in seasonal peak flow for all Basin Study model nodes, on the order of 50 percent for nodes in the upper basin and on the order of 30 percent for the Niobrara River near Spencer, Nebraska.

For the low flow season (generally defined as August through November), reductions in mean monthly unimpaired flow on the order of 10 to 20 percent are projected for the Central Tendency scenario.




**Mean Annual Precipitation** **Mean Annual Temperature** **Mean Annual Runoff**

**Figure ES-1.—Historical (1960-2010) and projected changes in mean annual precipitation (inches), temperature (°F), and runoff (inches) for the Central Tendency climate change scenario (2050s compared with historical).**




**Niobrara River above Box Butte (06454500)** **Niobrara River near Spencer (06465000)**

**Figure ES-2.—Summary of historical and projected mean monthly hydrographs of simulated natural streamflow by the VIC model.**

## Linkages of Climate Change Scenarios and Basin Study Models

The modeling framework for the Basin Study consists of two integrated models, namely encompassing UNW and CENEB portions of the study area (see illustrations of these modeled areas in figure 1 in Section I.A.2). Each of the integrated models (UNW and CENEB) is comprised of a series of models which

interact through data transfer. In each modeled region, a watershed model simulates surface water hydrology and agricultural water demands, a groundwater hydrology model simulates groundwater levels and baseflow contributions to streamflow, and a surface water operations model simulates the management of water in the region. The following paragraph outlines historical and climate change scenario data developed for various modeling components of the Basin Study by Reclamation's Technical Service Center. It should be noted that although the Technical Service Center provided inputs for modeling components, it did not implement them.

The watershed models for the UNW and CENEB subregions of the study area ingest daily precipitation, daily minimum and maximum air temperature, and daily reference ET at select climate stations. Reclamation's Technical Service Center developed historical and climate change scenario inputs of these variables. In addition, the UNW and CENEB subregion surface water operations models incorporate computed net evaporation rates for Box Butte and Merritt reservoirs as part of the water balance. Reclamation utilized the Complementary Relationship Lake Evaporation (CRLE) model (Morton et al., 1985) to compute historical and projected reservoir net evaporation. This methodology is consistent with Reclamation's WWCRA (2015). For Box Butte, the Central Tendency scenario indicates an increase of about 15 percent in net evaporation for the future time horizon 2030-2059. For Merritt, the Central Tendency indicates a median increase of about 2 percent.

Reclamation's Technical Service Center developed adjusted historical Merritt Reservoir inflows for the purpose of calibrating the CENEB surface water operations model, as well as adjusted Merritt Reservoir inflows for the Future No Action scenarios. Other model inputs were provided by Nebraska DNR and its contractors. Finally, Reclamation provided historical and projected temperature at National Weather Service (NWS) Cooperative Observer (Co-Op) stations closest to Box Butte and Merritt reservoirs, which are relevant to the recreation benefits analysis. Additional details regarding development of individual inputs are discussed in Section 4 of this technical report (also referred to as Appendix A to the Niobrara River Basin Study report).

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## Contents

## Tables

## Figures

## Acronyms

| | |
|---|---|
| °C | degrees Celsius |
| °F | degrees Fahrenheit |
| ASCE-EWRI | Environmental and Water Resources Institute of the American Society of Civil Engineers |
| Basin Study | Niobrara River Basin Study |
| cfs | cubic feet per second |
| CMIP3 | Coupled Model Intercomparison Project Phase 3 |
| CMIP5 | Couple Model Intercomparison Project Phase 5 |
| CENEB | Central Nebraska model region (includes Middle Niobrara, Lower Niobrara, Upper Elkhorn, Lower Elkhorn, Upper Loup, and Lower Loup Natural Resources Districts) |
| $CO_2$ | carbon dioxide |
| Co-Op | cooperative observer |
| DNR | Department of Natural Resources |
| EPA | Environmental Protection Agency |
| ET | evapotranspiration |
| GCM | General Circulation Model, or Global Climate Model |
| GHG | greenhouse gas |
| ID | identification number |
| in | inches |
| IPCC | Intergovernmental Panel on Climate Change |
| km | kilometer |
| NCA | National Climate Assessment |
| NOAA | National Oceanic and Atmospheric Association |
| NWR | National Wildlife Refuge |
| NWS | National Weather Service |
| P | precipitation |
| PDSI | Palmer Drought Severity Index |
| Prcp | precipitation |
| Reclamation | Bureau of Reclamation |
| SECURE | Science and Engineering to Comprehensively Understand and Responsibly Enhance |
| SWE | snow water equivalent |
| T | temperature |
| Tavg | average temperature |
| UNW | Upper Niobrara–White model region (includes Upper Niobrara–White Natural Resources Districts) |
| U.S. | United States |
| USGS | U.S. Geological Survey |
| VIC | Variable Infiltration Capacity hydrologic model |
| WaterSMART | Water Sustain and Manage America's Resources for Tomorrow |
| WWCRA | West-Wide Climate Risk Assessment |

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# I. Introduction

## A. Purpose, Scope, and Objective of Study

The Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (DNR) and the Bureau of Reclamation (Reclamation), which is authorized under the SECURE (Science and Engineering to Comprehensively Understand and Responsibly Enhance) Water Act (Title IX, Subtitle F of Public Law 111-11).

The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region on identification and evaluation of potential adaptation strategies which may reduce any identified gaps. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment ([WWCRA]; Reclamation, 2011; Reclamation, 2015) but contain additional information, if available. The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources for the Western United States (U.S.) by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build upon existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen evaluation metrics
- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The purpose of this report is to summarize the climate change analysis for the Basin Study and discuss development of climate related inputs by Reclamation's Technical Service Center for various modeling components of the Basin Study. It first provides a general basin scale assessment of historical and future water supply. The report then summarizes ways in which linkages between various Basin Study modeling components were developed to incorporate historical and projected climate and hydrologic information. Additional Basin Study technical reports supplement this analysis and contribute to the overall Basin Study report.

## 1. Federal WaterSMART Program

This section briefly discusses the ongoing federal Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which provides the underlying mechanism for conducting the Basin Study. The WaterSMART Program, established by the Secretary of Interior under Secretarial Order 3297, addresses an increasing set of water supply challenges, including chronic water supply shortages due to increased population growth, climate variability and change, and heightened competition for finite water supplies. The WaterSMART Program was developed as means of implementing the SECURE Water Act of 2009 (Public Law 111-11). The WaterSMART Program provides the scientific and financial tools and the collaborative environment needed to help balance water supply and demand through the efficient use of current supplies and the development of new supplies. Through WaterSMART, Reclamation is making use of the best available science in the assessments it conducts and the policies it employs. Results coming from this work have and will continue to inform the decisions of water managers who need reliable estimates of current conditions in the hydrologic cycle and projections of supply and demand in watersheds throughout the nation. Many examples of best available science are being developed through the WaterSMART Program. Much of that science can be accessed through the WaterSMART Clearinghouse, an online collaborative site where best practices and cost-effective technologies for water conservation and sustainable water strategies are shared with the public (http://www.doi.gov/watersmart/html/index.php).

## 2. Location and Description of Study Area

The Niobrara River Basin is located almost entirely within the state of Nebraska. Only small portions of its tributary area are located in Wyoming and South Dakota (approximately 4 and 12 percent, respectively). Each basin study is unique with respect to addressing relevant water supply and demand issues in its watershed. In the Niobrara River Basin, surface water and groundwater resources are used to supply water for agricultural uses, primarily. However, additional uses of the basin’s water resources include municipal use, hydropower, recreation, and ecosystem services.

Figure 1 illustrates the Basin Study area and includes other notable features within the basin. The basin has two Reclamation irrigation projections: the Mirage Flats Project (11,662 acres) located in the upper basin (near U.S. Geological Survey [USGS] gage ID [identification] 0645450, see figure 1) and the Ainsworth Unit (35,000 acres) located in the lower basin (near USGS gage ID 0649500, see figure 1). Spencer Hydropower is the single (private) hydropower facility in the basin, located near USGS gage ID 06465000 (see figure 1). In addition, a reach of the lower Niobrara River was designated as a National Wild and Scenic River in 1991. This Wild and Scenic River is located near the Fort Niobrara National Wildlife Refuge ([NWR], see figure 1).

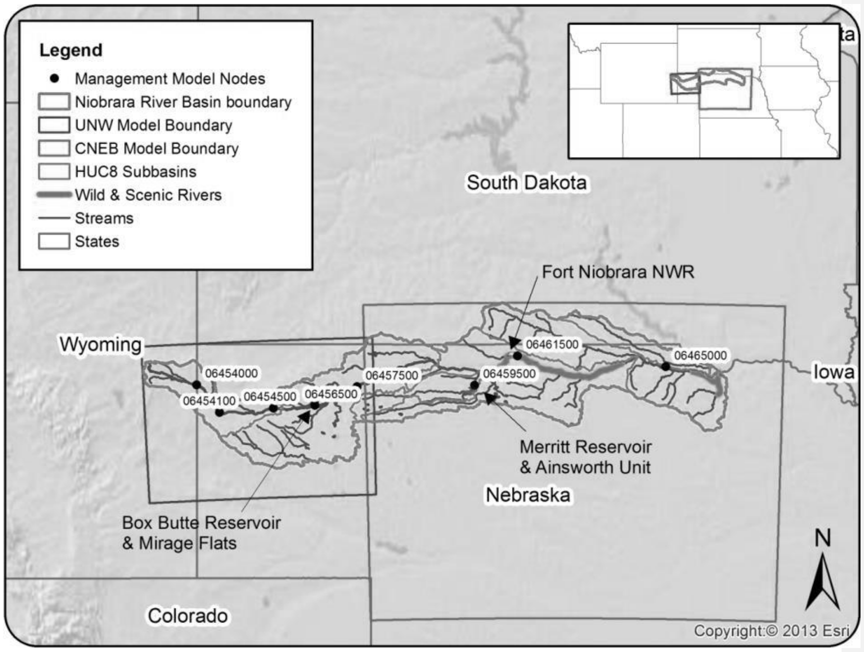



**Figure 1.—Overview map of Niobrara River Basin.**

Figure 1 also includes points which indicate the locations of model nodes for the water management models used as part of the Basin Study modeling framework. These nodes correspond with selected USGS streamflow gaging locations. These gaging locations are described in more detail in table 1.

## B. Summary of Previous and Current Studies

A large body of research has been conducted over the past ten or more years on climate change and how various regions of the U.S. might be affected. Most of this research has focused on large scale implications while providing limited regional scale information. The following section summarizes research that is relevant to the Niobrara River Basin, and shows that this analysis adds value to our understanding of climate change impacts in the region. The section relies on four primary sources which are comprised of synthesis reports of a wide range of climate change related research in the region. These sources are identified in table 2.

**Table 1.—Summary of Management Model Locations**

| USGS ID | Management Model Location | Latitude | Longitude |
|---|---|---|---|
| 06454000 | Niobrara River at Wyoming-Nebraska Stateline | 42.66 | –104.07 |
| 06454100 | Niobrara River at Agate, Nebraska | 42.42 | –103.79 |
| 06454500 | Niobrara River above Box Butte Reservoir, Nebraska | 42.46 | –103.17 |
| 06456500 | Niobrara River near Hay Springs, Nebraska | 42.48 | –102.69 |
| 06457500 | Niobrara River near Gordon, Nebraska | 42.64 | –102.21 |
| 06461500 | Niobrara River near Sparks, Nebraska | 42.90 | –100.36 |
| 06459500 | Snake River near Burge, Nebraska | 42.65 | –100.86 |
| 06465000 | Niobrara River near Spencer, Nebraska | 42.81 | –98.66 |

**Table 2.—References Supporting Summary of Previous and Current Studies**

| Citation | Title of Existing Synthesis Report |
|---|---|
| Reclamation (2013) | Third Edition Literature Synthesis on Climate Change Implications for Water and Environmental Resources |
| Shafer et al. (2014) | Climate Change Impacts in the U.S.: The Third National Climate Assessment, Chapter 19, Great Plains |
| U.S. Environmental Protection Agency (2014) | Climate Change Indicators in the United States, 2014, Third Edition |
| University of Nebraska-Lincoln (2014) | Understanding and Assessing Climate Change Implications for Nebraska |

Together, these sources provide a broad summary of existing scientific knowledge of historical climate and climate change impacts on the Niobrara River Basin and surrounding region. Information from these sources is summarized further in the sections below.

## 1. Historical Trends

The Niobrara River Basin extends across much of northern Nebraska, extending into southern South Dakota and into eastern Wyoming. Climate in Nebraska, as well as in the Niobrara River Basin, is well known for having a substantial moisture gradient from west to east, with the western portion being semiarid and the eastern portion being more humid. Annual precipitation totals for Nebraska range from 36 inches in the southeast to less than 15 inches in the northwest (University of Nebraska-Lincoln, 2014), while average annual temperatures range from about 55°F (degrees Fahrenheit) in the southeast to about 46°F in the northwest. Reclamation’s 2013 literature synthesis, which summarizes existing literature (published between 1994 and 2012) on historical trends in climate and hydrology, as well as projected future changes in the Great Plains region, summarizes trend analysis using the U.S. Historical Climatology Network. The analysis indicates an increase in annual precipitation of more than 4 percent in the northern Great Plains

and 10 percent in the southern Great Plains over the same period. The trend was more consistent in the southern Great Plains (Reclamation, 2013).

Historical climate trends reported by University of Nebraska-Lincoln (2014) indicate Nebraska has experienced an overall warming of about 1 degree F since 1895. Seasonally, the trends show greater warming in winter (defined as December - February) and spring (defined as March - May), 2.0°F and 1.8°F, respectively. Summer (defined as June – August) has a 1.0°F warming trend, while fall (defined as September – November) has no discernable historical temperature trend. This assessment reports no discernable trend in mean annual precipitation in Nebraska. However, trends in seasonal precipitation show a general increase in spring across the state, a small decrease in summer, and essentially no trend in fall and winter. Reclamation's 2013 literature synthesis indicates that, based on data from the U.S. Historical Climatology Network, temperatures increased approximately 1.85°F (1.02°C (degrees Celsius)) in the northern Great Plains to approximately 0.63°F (0.35°C) in the southern Great Plains between 1901 and 2008.

The University of Nebraska-Lincoln (2014) assessment indicates the length of the frost-free season in Nebraska has increased, anywhere from 5 to 25 days and on average by more than one week since 1895. In an analysis of the paleo-record, multiple lines of evidence suggest that drought was a dominant feature of climate during the period from 900 to 1300 A.D. The more recent 150 year period of record has been largely a wet period, which may exacerbate any overall drying and loss of water due to climate change in coming decades.

In addition to its west-east wetter climate gradient, Nebraska's climate is also variable and subject to extremes. As one example of its climate variability, an average of 40 percent of the annual precipitation typically falls from May through July, while only 5 to 7 percent of the annual total normally falls from December through February. In a typical winter across southeast Nebraska, 20 to 25 inches of snow are common, increasing to 40 to 45 inches across the northwestern corner of the state. As one example of its climate extremes, portions of the state experienced severe flooding in 2011 and the entire state was engulfed in an extreme drought in 2012, the driest and warmest year on record, when portions of the state recorded maximum daily temperatures exceeding 100°F for 30 days or more (University of Nebraska-Lincoln, 2014).

Brown and Mote (2009) performed a snowpack sensitivity study across the entire Northern Hemisphere and compared the results to observed conditions (1966–2007 National Oceanic and Atmospheric Administration [NOAA] satellite dataset) and to snow cover simulations from the Coupled Model Intercomparison Project Phase 3 (CMIP3). The least sensitive areas were found to be in interior regions, such as the interior US, with relatively cold and dry winters where precipitation plays a larger role in snow cover variability. Kunkel et al. (2009) found snowfall declines from 1920–1921 to 2006–2007 in the central Great Plains and large percentage increases in the lee of the Rocky Mountains and parts of the

north-central Great Plains. It should be noted, however, that it remains difficult to attribute historical precipitation variability to anthropogenic forcing (Hoerling et al., 2010). As an example, worldwide trends in observed mean and extreme precipitation trends show signs of the influence of human forcing of the climate, but climate models produce a notably weaker precipitation change signal than is seen in the observations. However, there is growing evidence of a linkage between the warming of the globe, arctic sea ice decline and extreme winters across the eastern two-thirds of the US, including the GP Region (Reclamation, 2013).

The Environmental Protection Agency (EPA) published a report titled "Climate Change Indicators in the United States" to communicate information about the science and impacts of climate change, assess trends in environmental quality, and inform decision-making. The third edition, published in 2014, indicates that average drought conditions across the nation have varied since records began in 1895. The 1930s and 1950s saw the most widespread droughts, while the period from about 1964-2013 has generally been wetter than average. However, specific trends vary by region. A more detailed index developed recently by EPA shows that between 2000 and 2013, roughly 20 to 70 percent of the U.S. experienced drought at any given time, but this index has not been in use for long enough to compare with historical drought patterns (EPA, 2014).

Although pine forests are not characteristic throughout Nebraska, the Pine Ridge region in the Western Niobrara River valley consists of Ponderosa pine forests. Repeated intense and uncharacteristic wildfires occurred in this region since 1994 and reduced forest cover from 250,000 acres to less than 100,000 acres. Intense burning has converted some of these forests to grassland, and projected increases in temperature and drought may threaten Nebraska's remaining pine forests. In addition, Nebraska's pine forests lost thousands of trees in the 2000s from Mountain Pine Beetle attacks, part of an outbreak affecting 35 million acres in North America. Engraver beetles (Ips species) are currently attacking and killing heat- and drought stressed pines across the Pine Ridge and Niobrara Valley (University of Nebraska-Lincoln, 2014).

## 2. Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) projections of future climate have been utilized in assessing projecting climate change impacts, including over Nebraska and the Niobrara River Basin. Reclamation, in its WWCRA (2011), reported on climate change implications for water supplies and related water resources within eight major Western U.S. river basins, including Great Plains Region's Missouri River Basin. The Great Plains regions are likely to continue to experience the kind of interannual to interdecadal variations in precipitation that they have experienced in the past. For the next few decades, these variations are likely to be superimposed upon background trends that, in

most cases, are likely to be subtle compared with the variations. Evapotranspiration (ET) demands and warm-season precipitation play a more prominent role in determining local hydrologic conditions in the Great Plains relative to water management and generally more so relative to the influence of headwaters snowpack and snowmelt timing. Future projections of precipitation for the southern Great Plains are further complicated by the limitations on the ability of climate models to portray the frequency and intensity of warm-season convection events or tropical storm systems tracking into the region (Reclamation, 2013).

According to Nebraska's climate change impacts assessment, which reports on analyses using climate projections from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 5 (CMIP5, described in Section 3.1), projected changes in temperature for Nebraska range from 4°F to 5°F (low emission scenarios) to 8°F to 9°F (high emission scenarios) by the late twenty-first century (2071-2099). High temperature stress days are projected to increase to 13-16 additional days that exceed 100°F across Nebraska, with a range from 10-21 days in the east to 21-37 days in the western part of the state. For Nebraska, the number of warm nights is expected to increase to an additional 20-25 nights for the lower emissions scenario and 25- 40 nights for the higher emissions scenario (where warm nights are defined as having a minimum temperature above 60°F). Winter and spring precipitation is expected to increase in the more northern states, with little change in precipitation for these two seasons for Nebraska. Projected changes in summer and fall precipitation are expected to be small in the Great Plains, with some possibility of reduced summer precipitation in the central Plains states (University of Nebraska-Lincoln, 2014).

The region frequently experiences a wide range of weather and climate hazards such as tornadoes, droughts, floods, and other severe weather events that result in significant economic losses and stresses to a fragile ecosystem. Climate change will further exacerbate those stresses and increase economic losses in the future (University of Nebraska-Lincoln, 2014). Gutowski et al. (2008) suggest that climate change likely will cause precipitation to be less frequent but more intense in many areas and suggests that precipitation extremes are very likely to increase, an effect already that is already observed (Min et al., 2011). In another study, the Palmer Drought Severity Index (PDSI) gives indications of a semi-permanent state of severe drought over the Great Plains in coming decades with climate change projections of rising temperatures and decreasing precipitation amounts (Reclamation, 2013). Hoerling et al. (2012) looked at the difference between projections of PDSI and soil moisture through the 21st century and found that the PDSI projections do lead to prolonged severe drought conditions. The soil moisture projections, however, point to a more modest drying with a much smaller change in drought frequency. In their view, if prolonged severe drought occurs in the near future, it will be due to lengthy periods of precipitation deficits.

Groundwater irrigation accounts for about 95 percent of all groundwater withdrawals, and Nebraska leads the nation in irrigated acres, the vast majority of which is sourced from groundwater (University of Nebraska-Lincoln, 2014).

Groundwater levels in Nebraska are closely related to climate variability, predominately because of the changing demand for irrigation. In Nebraska, a northwest-southeast gradient of observed annual precipitation (15-36 inches per year) and projected changes in heavy precipitation (0.4 to 1 inches during the 7 wettest days) illustrate the sensitivity of the western portion of the state to recurrent dry conditions.

### 3. Hydrological Projections

Projected changes in climate have implications for hydrology. Warming trends contribute to a shift in cool season precipitation towards more rain and less snow, which causes increased rainfall-runoff volume during the cool season accompanied by less snowpack accumulation. Generally speaking, the ensemble-median changes in climate based on CMIP3 projections (described in Section III.A) suggest that the greater Missouri River Basin (encompassing the Niobrara River Basin) will experience increasing mean-annual temperature and with precipitation change during the 21st century that varies from increases in more northerly subbasins to generally no change in more southerly subbasins. These changes are projected to be accompanied by decreasing trend in spring snow water equivalent (SWE), a decreasing trend in April–July runoff volume, increasing trends in December–March and annual runoff volumes, and reduced soil moisture levels (Reclamation, 2013).

It should be noted that uncertainties associated with the hydrologic analysis may impact results of climate change impacts studies. Vano et al. (2012) applied multiple land-surface hydrologic models in the Colorado River Basin under multiple, common climate change scenarios. Their results showed that runoff response to these scenarios varied by model and stemmed from how the models feature a collective of plausible hydrologic process portrayals, where a certain combination of process portrayal choices led to a model's simulated runoff being more or less sensitive to climate change. Although these results are most applicable to the Colorado River Basin, it is still expected that application of the models in Vano et al. (2012) to other Western U.S. basins would likewise show model-dependent runoff sensitivity to climate change (Reclamation, 2013).

### 4. Climate Change Impacts

Future climate and hydrologic projections in the Niobrara River Basin will impact various environmental resources pertinent to the Basin Study to varying degrees, including water resources, agriculture, aquatic ecosystems, invasive species, and other related resources.

If temperatures do increase during the growing season and precipitation decreases as indicated by the Third National Climate Assessment (NCA) 2014 report (Shafer et al., 2014), rural water supplies will be more vulnerable to shortages because of competition from irrigation. Irrigators may face allocation restrictions that set limits on the amount of water that can be applied on an annual basis. The

Third NCA suggests that rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs (Shafer et al., 2014).

By the year 2100, the Third NCA (Shafer et al., 2014) indicates that the frost-free season will increase by 30 to 40 days for Nebraska. Also, the Synthesis and Assessment Product 4.3 by the U.S. Climate Change Science Program (Lettenmaier et al., 2008) discusses the effects of climate change on agriculture and water resources (Hatfield et al., 2008). Findings suggest significant irrigation requirement increases for corn and alfalfa due to increased temperatures and carbon dioxide ($CO_2$) and reduced precipitation. Further, agricultural water demand could decrease due to crop failures caused by pests and disease exacerbated by climate change. On the other hand, agricultural water demand could increase if growing seasons lengthen and, assuming that farming practices could adapt to this opportunity, by planting more crop cycles per growing season. However, a shift toward earlier planting dates may not be viable because of the continued vulnerability to freeze damage in the spring (University of Nebraska-Lincoln, 2014). For example, the 2012, 2013, and 2014 growing seasons produced hard freeze conditions during the first half of May, even as favorable soil temperatures are occurring two weeks earlier when compared to the early 1980s. If precipitation amounts remain steady or decrease by the year 2100, ET demand will result in less moisture available to growing crops during their critical reproductive periods that occur in May (wheat), July (corn), and August (sorghum, soybean). During 2012, native vegetation broke dormancy a month earlier than normal and soil moisture reserves were depleted across most of the U.S. Corn Belt well before the critical pollination period was reached.

The Third NCA suggests that changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices (Shafer et al., 2014).

While all ecosystems in Nebraska will be affected by climate change, aquatic ecosystems (wetlands, lakes, streams, and rivers) may be the most highly impacted (University of Nebraska-Lincoln, 2014). Climate changes will alter both water quality and quantity. Increases in the frequency and intensity of high precipitation events, particularly in a landscape dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower stream flows and an increase in the frequency of stream segments being de-watered and wetlands drying up. Finally, increases in air temperature will result in increases in water temperature, causing a reduction in suitable habitat for cold-water dependent species such as trout.

Dunnell and Travers (2011) report that some spring flowering species have advanced their first flowering time, some fall species have delayed their first

flowering, and some species have not changed. Given the importance of flowering timing for reproductive success, the changing climate in the Great Plains is expected to have long-term ecological and evolutionary consequences for native plant species.

Covich et al. (1997) summarize available information on patterns of spatial climate variability and identify subregions of importance to ecological processes within the Great Plains. Climate sensitive areas of the Great Plains range from cold water systems (springs and spring-fed streams) to warmer, temporary systems (intermittent streams, ponds, pothole wetlands, playas).

Warmer water temperatures also could exacerbate invasive species issues (e.g., quagga mussel reproduction cycles responding favorably to warmer water temperatures); moreover, climate changes could decrease the effectiveness of chemical or biological agents used to control invasive species (Hellman et al., 2008). Warmer water temperatures also could spur the growth of algae, which could result in eutrophic conditions in lakes, declines in water quality (Lettenmaier et al., 2008), and changes in species composition. In addition, landscape fragmentation is increasing, for example, in the context of energy development activities in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles (Shafer et al., 2014). The magnitude of expected changes will exceed those experienced in the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts (Shafer et al., 2014).

# II. Historical Surface Water Availability

## A. Data and Models Used

The Basin Study utilizes regionalized soil water balance models (further referred to as watershed models), developed by the Upper Niobrara White (UNW) Natural Resources District, Nebraska DNR, and their contractors, to characterize surface hydrology, crop yields and irrigation water requirements and to ensure that water supplies and water uses were accounted for within a balanced water budget. Together with groundwater ( using MODFLOW) and surface water management models (using Stella and Excel software), these models were calibrated separately for the UNW region which includes UNW Natural Resources District and Central Nebraska (CENEB) to best represent simulated historical surface hydrology and crop dynamics in the watershed.

In this analysis, we employ the Variable Infiltration Capacity (VIC) surface hydrology model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) to evaluate historical trends in various elements of the natural surface water hydrology budget, and projected changes based on the Basin Study climate change scenarios. The VIC model is an advantageous tool for this type of evaluation since this model has been applied over the continental United States and beyond, and has been used in Reclamation for assessments under the WaterSMART Basin Studies program (e.g., Reclamation, 2011).

The VIC model is a spatially distributed hydrology model that solves the water balance at each model grid cell. The model initially was designed as a land-surface model to be incorporated in a Global Climate Model (GCM) so that land-surface processes could be more accurately simulated. However, the model now is run almost exclusively as a stand-alone hydrology model (not integrated with a GCM) and has been widely used in climate change impact and hydrologic variability studies. For climate change impact studies, VIC is run in what is termed the water balance mode that is less computationally demanding than an alternative energy balance mode, in which a surface temperature that closes both the water and energy balances is solved for iteratively. A schematic of the VIC hydrology and energy balance model is given in figure 2.

The VIC model may be implemented at any spatial resolution, adhering to a latitude-longitude grid. For this Basin Study, and for consistency with Reclamation's West-Wide Climate Risk Assessment, the model was implemented over the study area at 1/8 degree, or approximately 12 kilometer resolution. Physical characteristics of each cell are predefined within the study area to simulate runoff and other water/land/atmosphere interactions at each model grid cell. The VIC hydrology model uses daily meteorological data (precipitation, maximum temperature, minimum temperature and wind) along with land cover, soils, and elevation information at 1/8 degree grid scale to simulate hydrologic processes. The meteorological data used as input to the VIC model in this Basin

Study was developed by Maurer et al. (2002) and later extended through the year 2010. This dataset utilizes the National Weather Service (NWS) Cooperative Observer (Co-Op) network and Environment Canada daily station data as the primary sources for precipitation and temperature. The station data are processed to remove spatial and temporal inconsistencies and then interpolated to the 1/8 degree VIC model grid.

VIC provides a wide array of hydrologic outputs, including runoff, snow-water equivalent and ET, which are routinely analyzed to assess climate change impacts on watershed hydrology. Also, note that all of these outputs are produced at the native VIC model grid cell resolution of 1/8 degree, or approximately 12 kilometers.

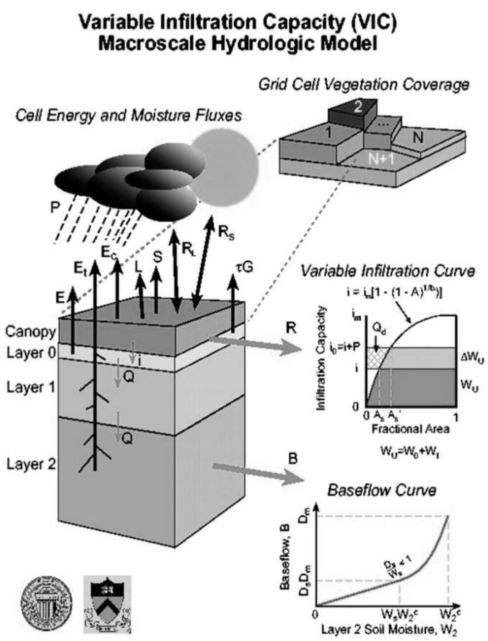



**Figure 2.—Illustration of VIC macroscale hydrologic model.**

The following section summarizes present surface water availability in the Niobrara River Basin as a whole. Specifically, historical climate, snowpack, ET, and runoff are presented as a way to characterize past trends and the basis for evaluating projected climate change impacts. It should be noted, however, that the Niobrara River Basin was divided into two regions, the UNW and the CENEB regions to enhance model computational efficiency (particularly for the groundwater models).

## B. Present Availability

Figure 3 illustrates variability and historical trends in six basin averaged water balance variables, including mean annual temperature, mean annual precipitation, mean January 1 snow water equivalent (liquid content of the snowpack), mean annual ET, mean annual runoff, and mean April-September runoff. SWE on January 1 was chosen for reporting due to the fact that the January 1 SWE has historically been the highest of any other month (comparing day 1 values for all months). The April – September runoff period was chosen because this period most generally corresponds with the irrigation season and represents the warmest half of the water year (typically October – September).

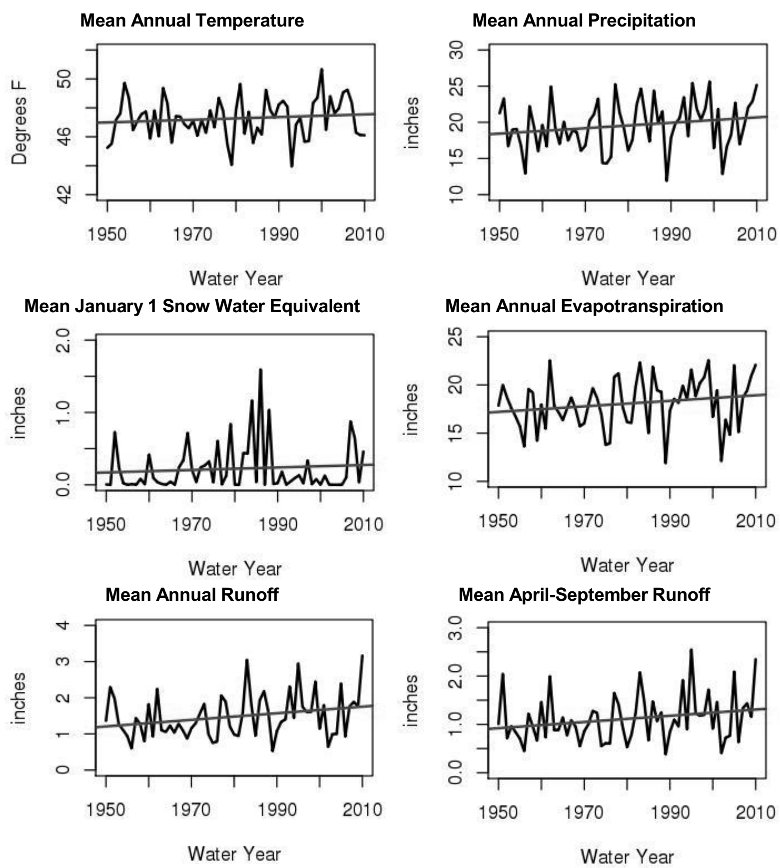



**Figure 3.—Summary of historical trends in the historical water balance in the Niobrara River Basin, 1950-2010.**

Historical trend analysis over the period 1950-2010 indicates an increasing trend in mean annual temperature and precipitation during this period, along with increases in ET and runoff (both annual and warm season, April – September, and an increase in January 1 SWE (month with historically highest computed snowpack). Table 3 summarizes these historical trends and computed change from 1950-2010. It should be noted that only the change in mean annual runoff is statistically significant, with a p-value less than or equal to 0.05. It should also be noted that the percent change in SWE and runoff between 1950 and 2010 are near or above 50 percent; however, the underlying values of SWE and runoff are small, generally less than 3 inches annually.

**Table 3.—Mean Change Over 1950-2010 Period (Water Years) Over the Niobrara River Basin**

Numbers in bold indicate statistical significance of trend at the 95th percentile level.

| | Basinwide Change | Percent Change | P value |
|---|---|---|---|
| **Precip** | + 2.2 in | + 12% | 0.1253 |
| **Tavg** | + 0.56 °F | -- | 0.3599 |
| **January 1 SWE** | + 0.1 in | + 61% | 0.4852 |
| **Annual ET** | + 1.7 in | +10% | 0.1264 |
| **Annual Runoff** | **+ 0.55 in** | **+45%** | **0.0363** |
| **Apr-Sep Runoff** | + 0.4in | +42% | 0.0710 |

Historical trends in precipitation and temperature computed using the Maurer et al. (2002) meteorological dataset, extended through 2010, are generally consistent with historical trends reported by the University of Nebraska-Lincoln (2014) study as well as by Reclamation's 2013 Literature Synthesis. Computed historical trends in mean annual precipitation in this study consist of an approximate 12 percent increase, while Reclamation (2013) found between a 4 and 10 percent increase over the northern and southern Great Plains regions, respectively. Computed historical trends in annual daily average temperature consist of a change of approximately 0.6°F, while the University of Nebraska-Lincoln report a statewide increase of about 1°F since 1895 and Reclamation (2013) reports an increase of approximately 1.85°F in the northern Great Plains to approximately 0.63°F in the southern Great Plains between 1901 and 2008. Although underlying station data used for analysis in the three studies may be the same, differences in results by these studies may be attributed to differences in processing of the data, as well as differences in reported spatial and temporal domains.

# III. Effects of Climate Variability and Change on Supply

As a step toward greater understanding of the implications of climate change on the Niobrara River Basin, this section first describes the approach for development of climate scenarios for the Basin Study, followed by discussions of approaches for evaluation of climate change impacts on surface water supplies. The assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture that have major implications for the watershed.

## A. Data and Models Used

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales. Changes in climate due to natural variability will continue to occur into the future, along with changes due to increased greenhouse gas (GHG) emissions from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

Arguably the most common approach for developing scenarios of future climate involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impacts studies. This can be done using dynamical downscaling, which involves using GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which involves using historical data as a way of statistically mapping GCM scale information to a finer resolution (in space and time). Statistical downscaling may involve delta method experiments, which involve computing period change values based on GCMs and applying them as perturbation factors to historical data. Numerous variations exist to this approach as well as hybrid approaches.

Climate projections are generally produced by internationally recognized climate modeling centers around the world and make use of GHG emissions scenarios, which include assumptions of projected population growth and economic activities. GCMs used to develop projections of future climate conditions typically have spatial resolutions on the order of 1 degree latitude by 1 degree longitude (approximately 100km by 100km over mid-latitudes).

However, water resources analysis and planning generally require information at much finer spatial scales. Many methods have been developed to downscale GCM projections to finer scales for use in water resources planning, all of which have strengths and weaknesses. Development of climate scenarios for the Basin Study relies on projections of future climate and hydrologic conditions developed under Reclamation's WWCRA (Reclamation, 2011). As part of the WWCRA, Reclamation, in collaboration with several other research groups, developed an archive of downscaled climate and hydrologic projections over the Western U.S. The archive of downscaled climate projections developed under WWCRA is based on a statistical downscaling procedure, where GCM projections are spatially downscaled based on statistical relationships between large-scale climate features and fine scale climate for the region. The projections are publically available through an online data portal (see http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html ).

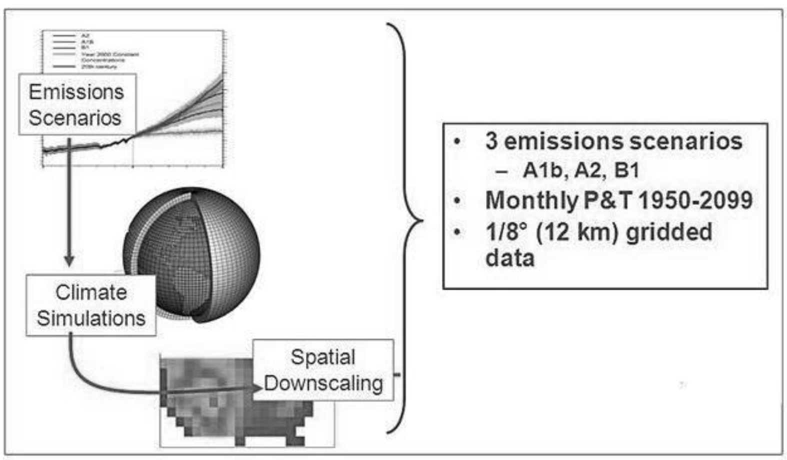



**Figure 4.—Summary of downscaled GCM key elements.**

The statistical downscaling process is illustrated in figure 4. The downscaled GCM projections used in the Basin Study are based on the CMIP3 (World Climate Research Programme's Coupled Model Intercomparison Project Phase 3; Meehl et al., 2007). These projections were the basis for analysis in the IPCC Fourth Assessment Report (IPCC, 2007).The emissions scenarios used in the downscaled GCM projections based on CMIP3 are A2 (high), A1b (medium), and B1 (low), and reflect a range of future GHG emissions. The emissions paths vary from lower to higher emissions rates, depending on assumptions of global technological and economic developments over the 21st century. Projections based on three CMIP3 emissions scenarios are available through the database mentioned above (A1B, A2, B1) for a total of 112 climate projections. Emission

scenarios exist that have both higher and lower GHG emissions than those considered in this Basin Study (e.g., A1fi). However, the three scenarios included in the analysis span a wide range of projected GHG and there are more GCM projections available based on these three emissions scenarios than any others.

This Basin Study uses the downscaled CMIP3 climate projections; however, new projections from the CMIP5 were recently published in May 2013. CMIP5 climate projections are based on emission scenarios referred to as representative concentration pathways (RCPs; Taylor et al., 2012). Even though CMIP5 projections are more current, it has not been determined that they are a more reliable source of climate projections compared to existing CMIP3 climate projections. At this time, CMIP5 projections should be considered an addition to (not a replacement of) the existing CMIP3 projections unless the climate science community can offer an explanation as to why CMIP5 should be favored over CMIP3.

Many of Reclamation's basin studies, including this Basin Study, utilize the downscaled climate and hydrology projection archive as the basis for developing climate scenarios. It should be noted that throughout this report, the term *climate projections* refers to raw or downscaled projections of future climate conditions produced by GCMs, whereas the term *climate scenarios* refers to climate and hydrologic datasets—including inputs to hydrologic, operations, and resource models—derived from climate projections in combination with historical, paleo, and/or other data sources. Climate scenarios are used to support detailed analysis of regional or basin-scale water supplies, demands, and operations under future conditions for a specific water resources planning study.

Three climate scenarios were developed for the Niobrara River Basin representing a projected range of climate and hydrologic conditions for the future period from 2030-2059. Downscaled climate and hydrology projections were obtained from the WWCRA projection archive for a region encompassing the Niobrara River Basin (figure 5). Note that this large-region view is only used to select projections to inform climate change scenarios. The large region is used to inform climate scenario development because of the coarser spatial scale of GCM projections. The region depicted in red in figure 5 is based on the following bounding latitude by longitude box: 41.6875 North through 44.0625 North Latitude; -105.0625 East through -97.5625 East Longitude.

Consistent with many complex planning studies, the Basin Study involves numerous modeling components which are brought together to evaluate watershed response to projected future climate conditions and to various water management alternatives. There is a need to adequately represent the projected range of future climate conditions, while also limiting the number of required simulations to maintain a manageable project scope. Therefore, analysis of the watershed under all available climate projections (112) was not practically feasible for this study, as it would require the same number of simulations per modeling component, multiplied by the number of management alternatives to be

considered by the study. To meet the needs of the Basin Study, three future climate change scenarios were developed as input to the hydrologic and management modeling framework to encompass range of projected water availability in the watershed in the 2030-2059 future time horizon. The following section describes the scenario development process for this study.

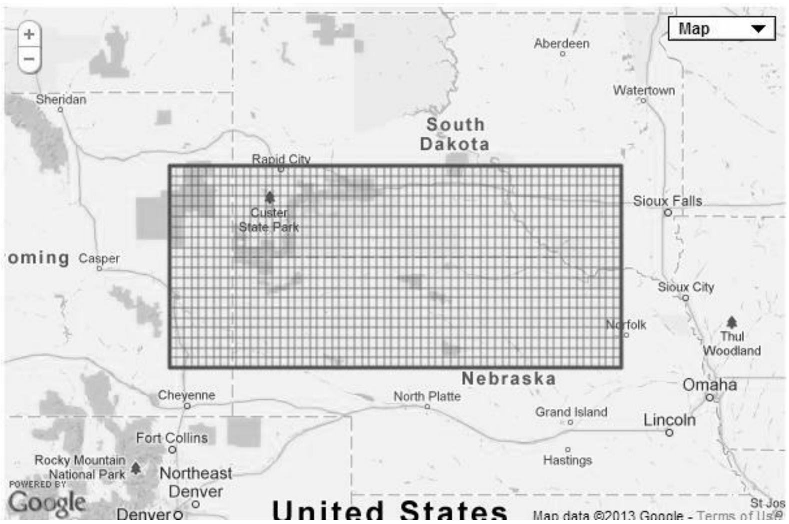



**Figure 5.—Map of region encompassing Niobrara River Basin that was used to develop climate scenarios.**

Projected climate change scenarios developed for the Basin Study are based on projected changes in three variables, comparing the future period 2030-2059 to the historical period 1970-1999. The three variables include:

1. mean annual water availability
2. mean summer precipitation (including June, July, August)
3. mean summer temperature (including June, July, August)

Water availability is defined as the mean of the annual difference between precipitation and ET. Mean summer (June – August) precipitation and temperature for the periods 1970-1999 and 2030-2059 were computed directly from the 112 statistically downscaled climate projections obtained from the WWCRA archive, while mean annual water availability is based on the corresponding hydrologic projections using the VIC model. VIC model simulations were completed as part of the WWCRA for each of the 112 CMIP3 future climate projections.

Depending on the preferences of a given study, the development of climate change scenarios may involve pooling of individual climate projections based on selected criteria or selection of individual climate projections for use as representative climate scenarios. Previous studies by Reclamation have explored the advantages and disadvantages of each approach (e.g., Reclamation, 2010; Reclamation, 2011). For the Basin Study, climate change scenarios were developed based on three individual climate projections selected directly from the 112 available CMIP3-based projections to represent low projected water availability (hereafter called the low scenario), median projected water availability (hereafter called the central tendency scenario), and high projected water availability (hereafter called the high scenario), as well as a range of projected change in summer temperature and precipitation. The selected projections that represent the three scenarios are summarized in table 4.

**Table 4.—Description of Niobrara River Basin Study Climate Change Scenarios**

| Climate Change Scenario | Description |
|---|---|
| **Low** | **giss_model_e_r.1.sresa2**<br>Low projected water availability (10th percentile) combined with drier summers (10th percentile precipitation) and greater summer warming (90th percentile temperature) |
| **Central Tendency** | **cccma_cgcm3_1.3.sresb1**<br>Central projected water availability (50th percentile) combined with central tendency of summer precipitation (50th percentile) and temperature (50th percentile) |
| **High** | **ncar_pcm1.1.sresa1b**<br>High projected water availability (90th percentile) combined with wetter summers (90th percentile precipitation) and less summer warming (10th percentile temperature) |

These scenarios were selected based on their ranked position with respect to projected change in mean annual water availability, summer precipitation (June – August), and temperature (June – August) from the historical period 1970-1999 to the future period 2030-2059. Projected change in precipitation and water availability were considered on a percent change basis, while temperature was considered based on difference in degrees Celsius. Projected changes in the above-mentioned variables were evaluated based on spatial means across the region (designated by region illustrated in figure 5) for the selected historical and future time periods. Preliminary scenario selection was carried out based on select percentile ranks of water availability: the 10th percentile rank was chosen to represent the low end of the projected range of water availability (generally drier conditions); the 90th percentile rank was chosen to represent the high end (generally wetter conditions); and the 50th percentile rank was chosen to represent the central tendency of the range of projections. Final scenario selection was determined by the study team to ensure that the selected scenarios represent the

projected ranges in all three variables. It should be noted that, although projections were selected based on projected changes computed as averages across a domain encompassing the Niobrara River Basin, the resulting climate scenarios maintain spatial variability across the domain. In other words, each scenario has potentially different projected climate changes from one portion of the watershed to another.

Figures 6 and 7 provide illustrations of the projection selection process. Specifically, figure 6 provides a schematic view of the approach, while figure 7 illustrates projected changes in mean summer (June – August) temperature and precipitation for the 2030-2059 period, compared with 1970-1999 for all 112 GCMs for which archive data are publicly available. Colored symbols in figure 7 illustrate the selected projections that comprise the climate change scenarios for the Basin Study. The blue symbol represents the low climate change scenario; the green symbol represents the central tendency climate change scenario; and finally, the orange symbol represents the high climate change scenario. The 10th, 50th, and 90th percentile changes in summer precipitation and temperature are illustrated by red (10th and 90th) and black lines (50th) in figure 7, to orient the reader.

Figure 7 shows that selected projections are close to the intersections of 10th, 50th, and 90th percentile change in summer precipitation and temperature. The projections closest to the intersections according to figure 7 may not have been selected because projected changes in mean annual water availability (P-ET) were taken into consideration in the projection selection process, along with summer precipitation and temperature. Select projections were chosen based on their collective proximity to these percentile values.

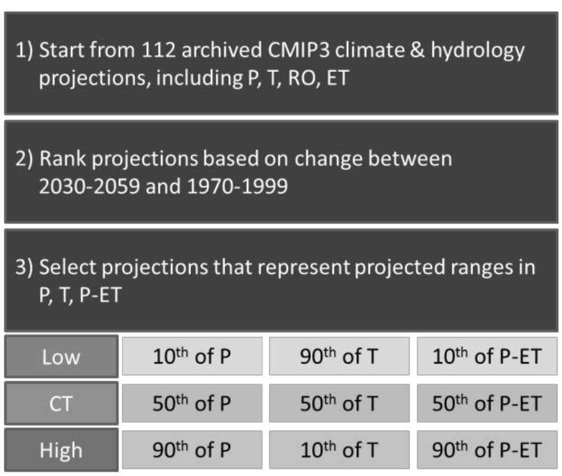



**Figure 6.—Overview of projection selection process.**

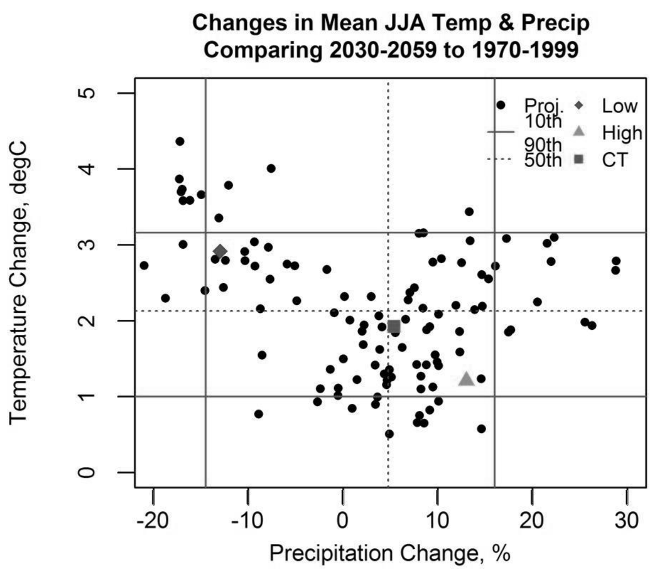



**Figure 7.—Projected change in mean summer (June – August) temperature and precipitation for 112 CMIP3 projections. Blue diamond indicates selected low scenario; green square indicates selected central tendency scenario; orange triangle indicates selected high scenario in terms of water availability.**

The selected Low scenario corresponds with a decrease in water availability by approximately 9 percent. The selected Central Tendency scenario corresponds with an increase in water availability of approximately 6 percent. The selected High scenario corresponds with an increase in water availability of approximately 37 percent. In summary, the range of projected water availability spans a modest decrease in water availability to a substantial increase in water availability. The fact that the selected central tendency projection indicates an overall increase in water availability (6 percent) means that a majority of the 112 CMIP3 GCM projections suggest an increase in water availability as opposed to a decrease. However, it should be noted that each of the 112 projections is deemed equally likely. Table 5 summarizes the projected change in each of the scenario selection variables between future and historical periods (2030-2059 and 1970-1999).

It should be noted that there are limitations associated with the choice of single GCM projections to represent each climate change scenario (Low, Central Tendency, and High). For example, Harding et al. (2012) suggest that impact analyses relying on one or a few climate scenarios are unacceptably influenced by the choice of projections. Also, Desser et al. (2013) underscore the importance of including a large number of projections from a given model in an analysis of climate change impacts because each model realization may contain different superposition of unforced and forced trends.

**Table 5.—Summary of Projected Changes in Selected Scenario Variables**

Results include those computed by the select projections for each scenario and those computed based on all 112 available CMIP3 projections.

| Parameter | Projection | Low | Central Tendency | High |
|---|---|---|---|---|
| **Mean Annual Water Availability** | Select Projection | -9% | +6.1% | +37% |
| | Based on 112 Projections | –16% | +10% | +50% |
| **Mean Summer Temperature (June–August)** | Select Projection | +2.9°C | +1.9°C | +1.2°C |
| | Based on 112 Projections | +3.3°C | +2.1°C | +.96°C |
| **Mean Summer Precipitation (June–August)** | Select Projection | -13% | +5.4% | +13% |
| | Based on 112 Projections | -15% | +4.7% | +17% |

Although it may be beneficial to evaluate climate change impacts based on numerous GCM projections, we found that projected changes in water availability, precipitation, and temperature computed based on the selected projections are comparable with corresponding 10$^{th}$, 50$^{th}$, and 90$^{th}$ percentile projections in these variables based on all 112 available CMIP3 projections. Table 5 illustrates the similarities in the projected changes. For each variable evaluated, projected changes based on selected projections (Low, Central Tendency, and High) are summarized along with projected changes based on all 112 projections. For summer precipitation, the ranges of these percentage values are less than 5 percent. For summer temperature, projected changes are within 0.5°C. For annual water availability, projected changes are more conservative than those based on all 112 projections (i.e., less change). It should be noted that projected changes for each variable based on all 112 projections are computed independently from each other, with the possibility of different ranks of GCMs for each variable.

The Basin Study utilizes historical and climate change scenario data to evaluate the implications of historical and future conditions on water supply and demand in a modeling framework, which is described in Section 4. Historical climate data (over a period 1960-2010), along with historical data and assumptions about water demands, allow for the tuning of individual models to observed historical conditions. Historical climate data is also used along with assumed current water demands (in this case set at 2010 levels) to establish a Baseline No Action scenario condition. The Baseline No Action scenario provides a benchmark to evaluate the effects of climate change on assumed future demands.

Future Low, Central Tendency, and High climate change scenario data (representing a future period of 2030-2059) is used along with assumed current water demands (set at 2010 levels) to explore future water supply and demand under a range of future climates. In the Basin Study, these future scenarios are

termed Future No Action Low (FNA Low), Future No Action Central Tendency (FNA CT), and Future No Action High (FNA High).

The Basin Study also evaluates the effects to two implemented alternatives on future water supply and demand. The details of the management alternatives are described in detail in Appendix F, the integrated water management modeling report. Generally, the first alternative includes changing the location of surface water diversion from the Niobrara River to the Mirage Flats Irrigation District to reduce conveyance losses in the current canal system. The second alternative includes using existing canal systems to recharge the groundwater system during periods of excess available water. The same Future Low, Central Tendency, and High climate change scenario data described above (representing a future period of 2030-2059) are used along with assumed demands under the two selected management alternatives. In the Basin Study, these future scenarios are termed Future with Alternative Low (FA1 Low or FA2 Low), Future with Alternative Central Tendency (FA1 CT or FA2 CT), and Future with Alternative High (FA1 High or FA2 High). It should be noted that Future No Action and Future with Alternatives use same future climate scenarios.

## B. Future Availability

Future water supply availability is described in this section by first evaluating projections of future temperature and precipitation, which drive hydrology. Following an assessment of projected future temperature and precipitation is an evaluation of projected future water balance variables pertinent to the Niobrara River Basin. Finally, an evaluation of projected changes in future unimpaired (or natural) streamflow is provided for selected locations in the basin that correspond with nodes in the groundwater, soil water balance, and surface water operations models.

### 1. Projections of Future Climate

Annual timeseries of mean annual precipitation (total) and temperature (average) are provided in figure 8, covering the period 1950–2099 (water years 1951-2099) for all GCMs that were used to inform selection of Basin Study climate change scenarios. To estimate total annual precipitation for the basin, basin-wide average precipitation (average across the grid cells in the basin) was first calculated for each month of the water years 1950–2099. These basin average monthly precipitation values then were summed for each water year 1951-2099 to obtain the annual total precipitation. To estimate basin mean temperature, average monthly temperature was calculated from all the grid cells in the basin for each month of the water years 1951–2099. These monthly temperatures for any given year next were averaged across the grid cells in the basin to estimate the basin-wide annual mean temperature. The annual time series for all the 112 GCM projections were calculated and the results are presented to reflect the central

tendency of the projections as well as the range. The central tendency is measured using the ensemble median. The 5th and 95th percentiles from the 112 GCM projections provide the lower and upper uncertainty bounds in the envelope of projections through time.

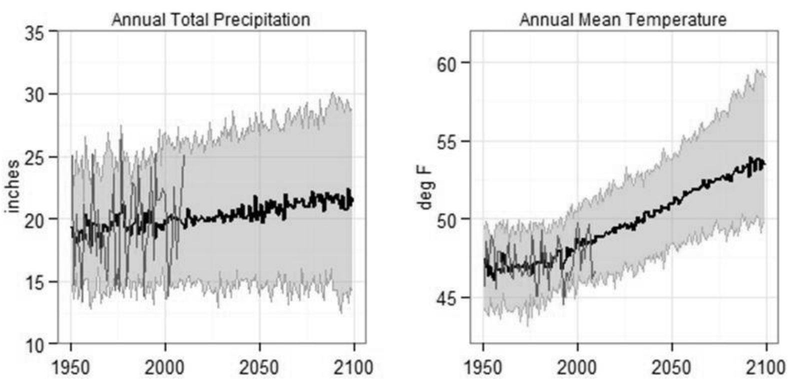



**Figure 8.—Projected mean annual precipitation (left) and temperature (right) averaged over the Niobrara River Basin for each of 112 archived CMIP3 climate projections from Reclamation's West-Wide Climate Risk Assessment. Heavy black line indicates annual median value. Heavy red line indicates basin averaged historical mean annual values based on Maurer et al. (2002) meteorological forcing dataset.**

The heavy black line in figure 8 is the annual time series of 50th percentile values (i.e., ensemble median). The shaded area is the annual time series of 5th to 95th percentiles. The heavy red line is the observed timeseries from the meteorological dataset used as the basis for historical model simulations for the Basin Study.

The annual total precipitation over the basin shows a somewhat increasing trend over the period from 1950 through 2099. The range of projections (as defined as the spread between 5th and 95th percentiles, or the width of the purple band) appears to expand through time indicating that model projections diverge into the future. The mean annual temperature over the basin shows an increasing trend and an expansion of the band of uncertainty over time. It should be noted that projected annual precipitation (particularly the median) is largely within the range of historical variability, whereas projected annual temperature at the end of this century is largely outside of the range of historical variability. The red lines showing observed mean annual precipitation and temperature highlights the year to year variability the Niobrara River Basin has experienced between 1950 and 2010, in part due to natural climate cycles outside of human induced climate change. This natural variability will continue in the future, as opposed to a monotonic or stepwise change through time.

## 2. Projections of Future Surface Hydrology

Historical and projected changes in climate and water balance variables are summarized in this section for each of the three climate change scenarios developed for the Basin Study. Climate change scenario development is described in detail in Section 3.1. Specifically, the Low scenario represents projected low water availability and generally corresponds with hotter and drier future climate. The Central Tendency scenario represents the middle-of-the-road water availability and generally corresponds with the central tendency of all available GCM projections for the chosen future time horizon. The High scenario represents high projected water availability and generally corresponds with wetter and less warm future climate. Together, the climate change scenarios are intended to represent a range of projected future conditions.

The following figures in this section consist of spatial plots that summarize climate and water balance variables averaged over select zones. The zones, which are illustrated in figure 9 by colored polygons, correspond with the modeled runoff zones by the watershed and groundwater models (for UNW and CENEB subregions). Runoff zones represent major subbasins of the Niobrara River that correspond with USGS gage locations. There are five runoff zones in the UNW subregion of the study area, while there are three runoff zones in the CENEB subregion of the study area. Runoff zones are equivalent to the upstream contributing area to each of the model nodes from table 1, subtracting any upstream zone areas. The table 1 model nodes are included in figure 9 for additional reference.

Figure 10 illustrates historical (1960-2010) and projected future (2030-2059) mean annual precipitation for the eight modeled zones within the basin. The figure indicates that the eastern part of the basin is historically wetter than the western part of the basin, which is consistent with analysis in Section 2.2. The Central Tendency climate change scenario indicates that the basin will experience an increase in mean annual precipitation of approximately 7 to 8 percent depending on the zone. The Low scenario indicates a change in precipitation from a decrease of 3 percent in the eastern part of the basin to an increase of 2 percent in the western part of the basin. The High scenario indicates an increase in mean annual precipitation by a range of 10 to 16 percent, with a greater increase in the eastern part of the basin. Data supporting the projected changes illustrated in figure 10 are provided in tables 6 and 7.

Figure 11 illustrates historical and projected changes in mean annual temperature for the eight modeled zones within the basin. The top panel showing historical temperature averaged from 1960-2010 for each zone indicates higher temperatures in the eastern part of the basin (approximately 48°F on average) and lower temperatures in the western part of the basin (approximately 45°F on average). Projected changes in temperature range from 2.5°F (High scenario) to about 5.5°F (Low scenario), without a substantial spatial gradient across zones.

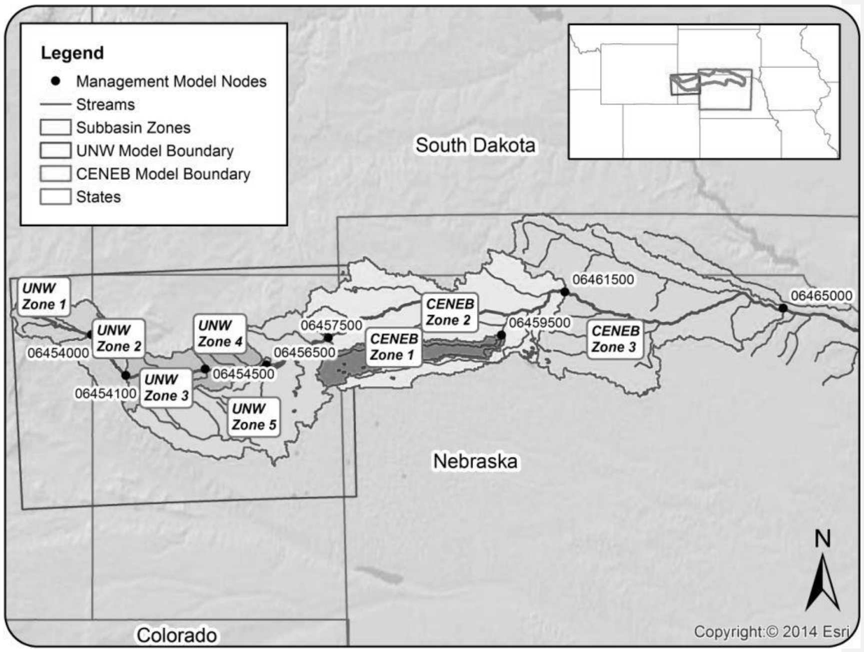



**Figure 9.—Summary zones (indicated by colored polygons) for climate change impact analysis.**

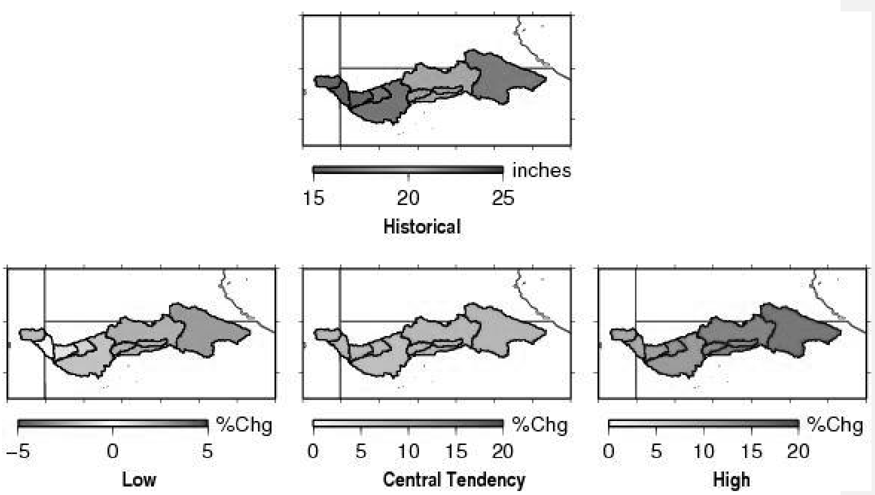



**Figure 10.—Historical (1960-2010) and projected changes in mean annual precipitation (inches) for three future scenarios (2050s compared with historical).**

**Table 6.—Historical (1960-2010) and Projected Climate and Water Balance Variables Based on VIC Model Simulations for Three Future Scenarios (2050s compared with historical)**

| Variable | Scenario | UNW Zone 1 | UNW Zone 2 | UNW Zone 3 | UNW Zone 4 | UNW Zone 5 | CENEB Zone 1 | CENEB Zone 2 | CENEB Zone 3 | Basin |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean Annual Precipitation (in) | Historical | 15.73 | 15.32 | 15.60 | 16.67 | 16.51 | 19.10 | 19.48 | 22.27 | 19.56 |
| | Low | 16.03 | 15.31 | 15.49 | 16.46 | 16.22 | 18.68 | 19.03 | 21.62 | 19.15 |
| | Central Tendency | 16.97 | 16.51 | 16.81 | 17.97 | 17.73 | 20.59 | 21.06 | 24.12 | 21.10 |
| | High | 17.29 | 16.82 | 17.29 | 18.71 | 18.42 | 21.67 | 22.25 | 25.79 | 22.33 |
| Mean Annual Temperature (°F) | Historical | 44.58 | 45.26 | 45.86 | 46.74 | 46.98 | 46.95 | 47.17 | 48.24 | 47.27 |
| | Low | 49.72 | 50.40 | 51.00 | 51.86 | 52.10 | 52.06 | 52.29 | 53.51 | 52.45 |
| | Central Tendency | 47.90 | 48.54 | 49.11 | 49.95 | 50.18 | 50.09 | 50.29 | 51.36 | 50.43 |
| | High | 47.00 | 47.69 | 48.28 | 49.13 | 49.43 | 49.47 | 49.70 | 50.89 | 49.82 |
| Mean Annual Runoff (in) | Historical | 0.85 | 0.82 | 0.82 | 1.13 | 0.92 | 0.92 | 1.03 | 1.36 | 1.16 |
| | Low | 0.85 | 0.79 | 0.77 | 1.06 | 0.85 | 0.84 | 0.94 | 1.23 | 1.07 |
| | Central Tendency | 0.98 | 0.95 | 0.94 | 1.28 | 1.05 | 1.04 | 1.17 | 1.54 | 1.31 |
| | High | 1.00 | 0.97 | 0.99 | 1.37 | 1.11 | 1.14 | 1.29 | 1.75 | 1.47 |
| Mean April - September Runoff (in) | Historical | 0.63 | 0.65 | 0.66 | 0.91 | 0.75 | 0.73 | 0.81 | 1.03 | 0.895 |
| | Low | 0.61 | 0.60 | 0.60 | 0.83 | 0.67 | 0.64 | 0.71 | 0.88 | 0.785 |
| | Central Tendency | 0.75 | 0.77 | 0.78 | 1.08 | 0.88 | 0.86 | 0.96 | 1.24 | 1.063 |
| | High | 0.71 | 0.72 | 0.75 | 1.05 | 0.85 | 0.86 | 0.97 | 1.27 | 1.070 |
| Mean Annual Evapotranspiration (in) | Historical | 14.75 | 14.40 | 14.70 | 15.42 | 15.48 | 18.09 | 18.31 | 20.34 | 18.06 |
| | Low | 15.04 | 14.42 | 14.64 | 15.29 | 15.28 | 17.78 | 18.00 | 20.06 | 17.86 |
| | Central Tendency | 15.75 | 15.43 | 15.79 | 16.55 | 16.56 | 19.45 | 19.72 | 21.95 | 19.43 |
| | High | 16.03 | 15.70 | 16.21 | 17.15 | 17.13 | 20.29 | 20.57 | 22.58 | 20.07 |

17-01174_012426;17-01174_012426;17-01174_012427;17-01174_012428;17-01174_012429;17-01174_012430;1...



**Table 7.—Historical (1960-2010) and Projected Changes in Climate and Water Balance Variables Based on VIC Model Simulations for Three Future Scenarios (2050s compared with historical)**

| Variable | Scenario | UNW Zone 1 | UNW Zone 2 | UNW Zone 3 | UNW Zone 4 | UNW Zone 5 | CENEB Zone 1 | CENEB Zone 2 | CENEB Zone 3 | Basin |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean Annual Precipitation (in) | Historical | 15.73 | 15.32 | 15.60 | 16.67 | 16.51 | 19.10 | 19.48 | 22.27 | 19.56 |
| | Low | 1.9% | -0.1% | -0.7% | -1.2% | -1.8% | -2.2% | -2.3% | -2.9% | -2.1% |
| | Central Tendency | 7.8% | 7.8% | 7.7% | 7.8% | 7.4% | 7.8% | 8.1% | 8.3% | 7.9% |
| | High | 9.9% | 9.8% | 10.8% | 12.2% | 11.5% | 13.5% | 14.3% | 15.8% | 14.2% |
| Mean Annual Temperature (°F) | Historical | 44.58 | 45.26 | 45.86 | 46.74 | 46.98 | 46.95 | 47.17 | 48.24 | 47.27 |
| | Low | 5.14 | 5.14 | 5.14 | 5.13 | 5.12 | 5.11 | 5.12 | 5.26 | 5.19 |
| | Central Tendency | 3.32 | 3.28 | 3.24 | 3.21 | 3.21 | 3.14 | 3.12 | 3.12 | 3.16 |
| | High | 2.42 | 2.43 | 2.41 | 2.40 | 2.45 | 2.52 | 2.53 | 2.65 | 2.55 |
| Mean Annual Runoff (in) | Historical | 0.85 | 0.82 | 0.82 | 1.13 | 0.92 | 0.92 | 1.03 | 1.36 | 1.16 |
| | Low | 0.8% | -3.5% | -5.9% | -5.8% | -7.4% | -9.4% | -8.7% | -8.9% | -7.7% |
| | Central Tendency | 16.1% | 15.7% | 14.3% | 14.0% | 13.6% | 13.3% | 13.7% | 13.6% | 13.2% |
| | High | 18.4% | 18.1% | 20.6% | 21.9% | 20.9% | 24.1% | 25.2% | 29.2% | 26.7% |
| Mean April - September Runoff (in) | Historical | 0.63 | 0.65 | 0.66 | 0.91 | 0.75 | 0.73 | 0.81 | 1.03 | 0.90 |
| | Low | -3.4% | -6.8% | -9.3% | -9.1% | -10.7% | -12.6% | -12.2% | -14.3% | -12.3% |
| | Central Tendency | 19.2% | 18.8% | 18.1% | 18.1% | 17.5% | 18.2% | 18.8% | 20.3% | 18.8% |
| | High | 12.3% | 11.4% | 13.9% | 15.5% | 14.2% | 17.8% | 19.1% | 23.1% | 19.5% |
| Mean Annual Evapotranspiration (in) | Historical | 14.75 | 14.40 | 14.70 | 15.42 | 15.48 | 18.09 | 18.31 | 20.34 | 18.06 |
| | Low | 2.0% | 0.2% | -0.5% | -0.9% | -1.3% | -1.7% | -1.7% | -1.4% | -1.1% |
| | Central Tendency | 6.8% | 7.1% | 7.4% | 7.3% | 7.0% | 7.5% | 7.7% | 7.9% | 7.5% |
| | High | 8.7% | 9.0% | 10.2% | 11.2% | 10.7% | 12.2% | 12.4% | 11.0% | 11.1% |

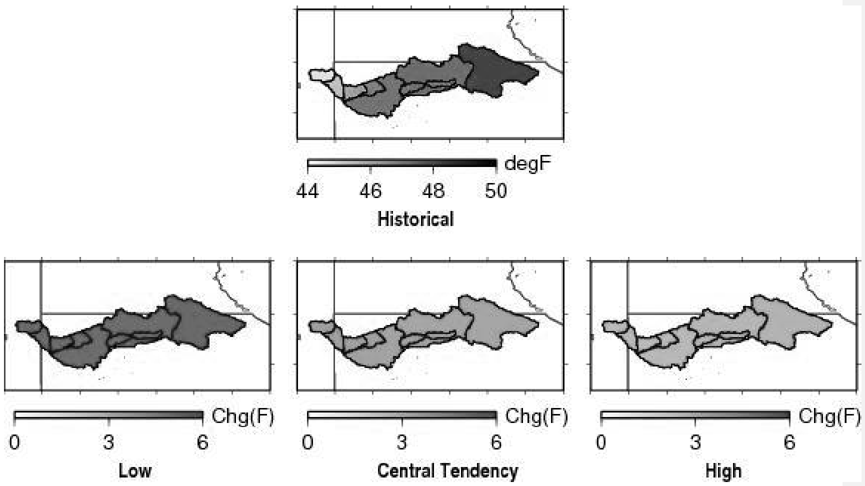



**Figure 11.—Historical (1960-2010) and projected changes in mean temperature (°F) for three future scenarios (2050s compared with historical).**

The VIC model was used to evaluate potential impacts of climate change on natural surface hydrology as part of the Basin Study. Although this model was not utilized as one of the model components to quantify historical and future water supply gaps in the basin, it is a valuable tool for exploring regional surface hydrology in regions with limited measurements. Results from the model may provide additional context for the assessment of current and future surface hydrology.

Figure 12 illustrates historical and projected mean annual runoff as computed by the VIC hydrologic model. The top panel, which summarizes historical runoff by model zone, indicates the eastern part of the basin experiences higher mean annual runoff that the western part of the basin (1.5 inches compared with 1 inch). It should be noted that about 95 percent of mean annual precipitation results in ET, leaving only about 5 percent to surface runoff. Projected changes in runoff based on the three selected climate change scenarios indicate a range of about -9 percent (Low scenario in the eastern portion of basin) to about +29 percent (High scenario in the western portion of the basin) in mean annual runoff, with an average increase of about 13 percent across the basin for the Central Tendency scenario.

About 75 percent of mean annual runoff occurs in the warm season (defined as April – September) as a result of monsoon related precipitation during that period. Projected changes in April-September runoff based on the three selected climate change scenarios indicate a range of about -14 percent (Low scenario in the eastern portion of basin) to about +23 percent (High scenario in the western

portion of the basin) in mean annual runoff, with an average increase of about 19 percent across the basin for the Central Tendency scenario.

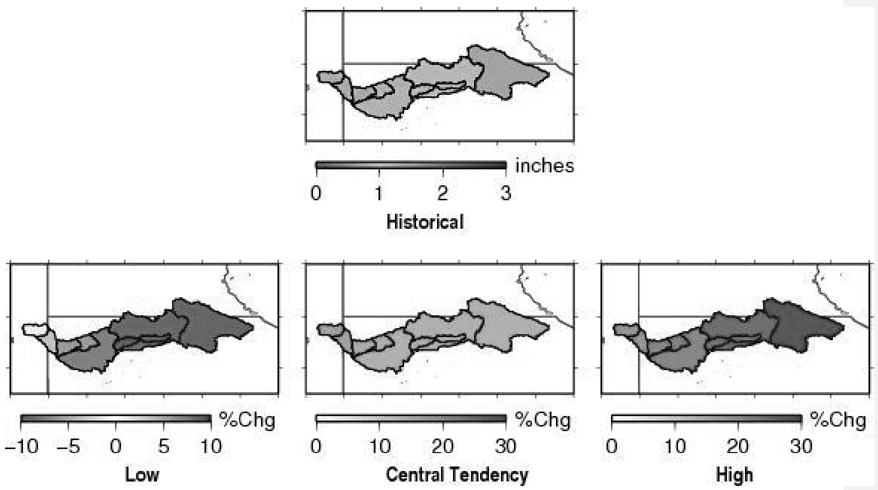



**Figure 12.—Historical (1960-2010) and projected changes in mean annual runoff (inches) for three future scenarios (2050s compared with historical).**

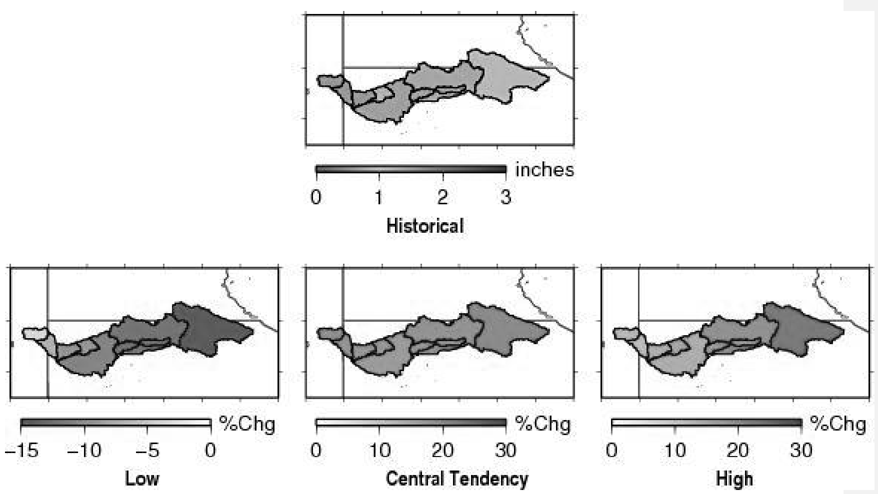



**Figure 13.—Historical (1960-2010) and projected changes in mean warm season (April September) runoff (inches) for three future scenarios (2050s compared with historical).**

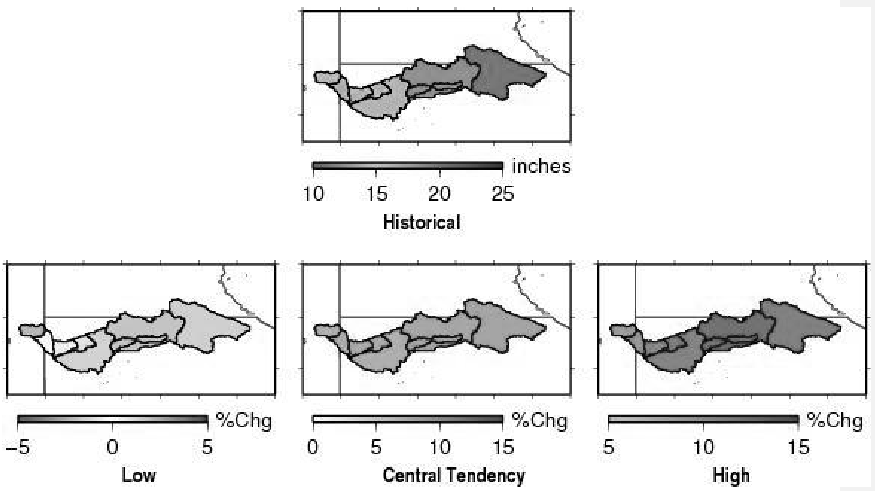



**Figure 14.—Historical (1960-2010) and projected changes in mean annual ET from natural vegetation (inches) for three future scenarios (2050s compared with historical).**

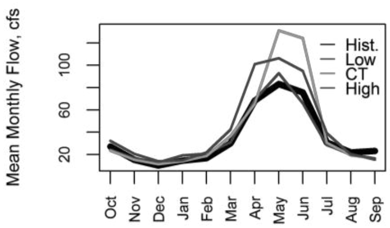
As discussed above, ET consumes about 95 percent of mean annual precipitation in the basin. Historically (average over 1960-2010) ET ranges from about 15 inches in the western part of the basin to 20 inches in the eastern part of the basin. Projected changes in ET as computed by the VIC model range from about a 1 percent decrease (Low) to a 11 percent increase (High), both in the eastern part of the basin. The central tendency scenario indicates about a 7.5 percent increase in ET Basin-wide, primarily as a result of projected increases in mean annual precipitation for the same scenario.

Results from VIC model simulations of historical (1960-2010) and projected future conditions (2030-2059) for all scenarios indicate a warmer future climate. Projected future precipitation, according to the three climate change scenarios developed, may range from a slight decrease to a more substantial increase, depending on the scenario considered and spatial location within the basin. The best available science indicates that no single climate scenario may be considered more likely than another. As such, a range of future conditions are taken through the entire modeling sequence, from surface and groundwater hydrology simulations to surface water operations simulations including facilities and operations.

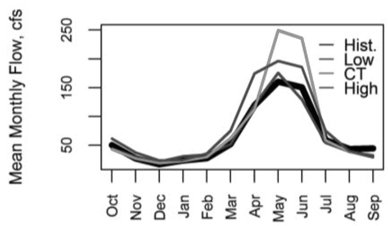
## 3. Projections of Unimpaired Streamflow

Evaluation of projections of unimpaired streamflow is beneficial for isolating the implications of climate change on hydrology, without the influence of changes in management. Projected changes in managed flows along with hydrology are

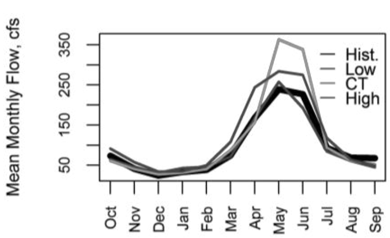
evaluated in a separate technical report. The VIC model, along with a separate streamflow routing routine, was used to develop historical and projected natural streamflow for the chosen future time horizon at model nodes used throughout the Basin Study (refer to table 1). Figures 15 and 16 illustrate historical and projected mean monthly hydrographs for the three climate change scenarios considered by the study. The historical hydrographs are computed over the 1960-2010 historical period, while the projected hydrographs are representative of climate over the 2030-2059 future time horizon.



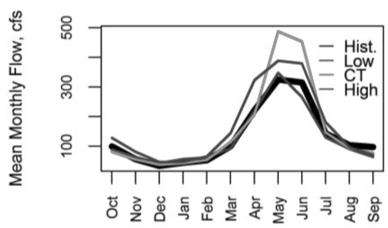

**Niobrara River at Stateline (06454000)**



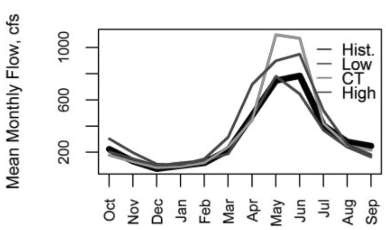

**Niobrara River at Agate (06454100)**




**Niobrara River above Box Butte (06454500)**




**Niobrara River at Hay Springs (06456500)**




**Niobrara River near Gordon (06457500)**

**Figure 15.—Summary of projected and historical mean monthly hydrographs of natural streamflow in UNW model region.**

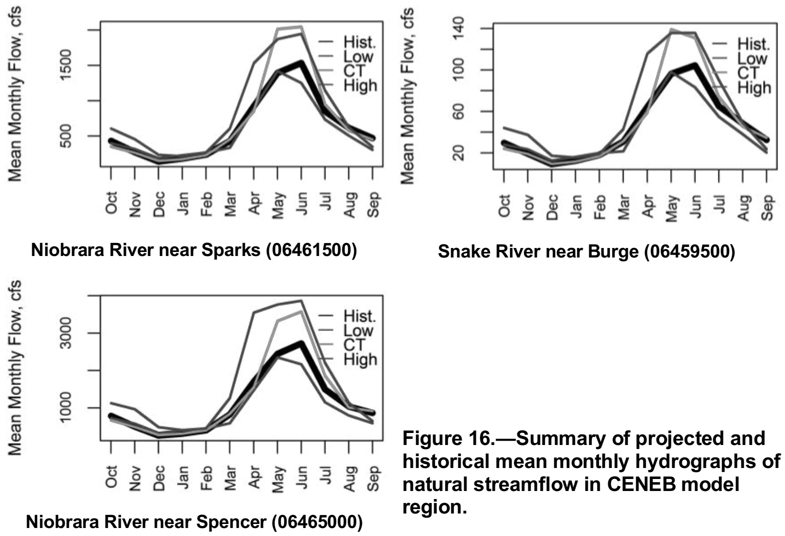



**Figure 16.—Summary of projected and historical mean monthly hydrographs of natural streamflow in CENEB model region.**

Historically, unimpaired streamflow in the basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Projected mean monthly unimpaired streamflow for the Central Tendency scenario indicates a substantial increase in seasonal peak flow for all Basin Study model nodes, on the order of 50 percent for nodes in the upper basin and on the order of 30 percent for the Niobrara River near Spencer, Nebraska. For the low flow season (generally defined as August through November), reductions in mean monthly unimpaired flow on the order of 10 to20 percent are projected for the Central Tendency scenario.

For the Low scenario (corresponding with a hot/dry projected climate), any projected changes in mean monthly unimpaired streamflow are modest. Increases in mean monthly flow are projected for November and December at most model nodes in the basin, on the order of 10 to 30 percent. The Low scenario also indicates a projected shift in seasonal peak flow by approximately one month (generally shifting to May for all sites).

For the High scenario (corresponding with less warm, along with wetter conditions), the mean annual streamflow volume increases, corresponding with projected increases in mean flows for most months of the year. Projected changes range from about 5 percent in January to 50 percent or more in fall months and in May through June.

It should be noted that historical and projected unimpaired flow are not meant to reflect actual flow measured in the Niobrara River and its tributaries. Actual flow

may deviate substantially from unimpaired values, due to the effects of water deliveries, storage, and other management effects. This analysis, in conjunction with the surface water operations models used in the Basin Study, together provide a broader understanding of projected hydrologic and management changes due to changes in future climate, and by extension a broader understanding of gaps in water supply and demand.

Tables 8 and 9 summarize the data used to support figures 15 and 16.

## 4. Groundwater Impacts

Groundwater supply is an important component of the overall water balance in the Niobrara River Basin. The regional agriculture industry has historically relied on groundwater supplies, in particular as a way of supplemental surface water supplies in drier years. In the Basin Study, we evaluate baseline and projected groundwater supplies in Appendix B, the groundwater modeling report. Baseline groundwater supplies are defined as a result of the Baseline No Action scenario. In the Baseline No Action scenario, historical climate (1960-2010) is used to inform a groundwater model. However, as discussed in Section 3.1, this is not a true historical simulation because current levels of agricultural development (defined by year 2010) are assumed to be unchanging into the future. This allows for the evaluation of climate change impacts alone, without the confounding factor increased groundwater development since about 1970.

Projected future groundwater supplies are evaluated using groundwater model simulations using Future No Action scenarios. These scenarios combine the same level of agricultural development assumed for the Baseline No Action scenario (defined by year 2010) and the same three future climate scenarios defined earlier in Section 3 of this technical report, namely Low, Central Tendency, and High.

The reader is referred to Appendix B, the groundwater modeling report for further analysis of climate change impacts on groundwater supplies in the basin. However, Section 4 of this report describes how the climate change scenarios defined in this technical report inform other components of analysis in the Basin Study.

**Table 8.—Historical (1960-2010) and projected unimpaired (natural) streamflow (cfs) based on VIC model simulations for three future scenarios (2050s compared with historical)**

| Variable | Scenario | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Niobrara River at Stateline (UNW Zone 1) | Historical | 27.25 | 15.28 | 10.13 | 14.47 | 16.74 | 30.07 | 68.24 | 83.25 | 75.69 | 30.76 | 21.85 | 23.11 |
| | Low | 24.27 | 16.70 | 12.98 | 19.18 | 20.70 | 30.95 | 69.05 | 92.91 | 66.03 | 28.52 | 20.57 | 15.52 |
| | Central Tendency | 23.67 | 15.31 | 11.31 | 13.87 | 18.64 | 36.46 | 65.47 | 131.2 | 124.3 | 30.64 | 19.50 | 16.57 |
| | High | 32.24 | 20.49 | 13.88 | 14.84 | 21.79 | 42.33 | 101.0 | 106.2 | 94.97 | 39.17 | 19.94 | 16.56 |
| Niobrara River at Agate (UNW Zone 2) | Historical | 50.66 | 27.56 | 17.25 | 23.73 | 27.74 | 52.29 | 119.1 | 160.3 | 150.8 | 59.28 | 43.49 | 44.65 |
| | Low | 44.49 | 30.02 | 22.00 | 31.16 | 33.73 | 51.97 | 119.8 | 175.6 | 129.4 | 54.42 | 39.46 | 29.61 |
| | Central Tendency | 43.57 | 27.19 | 19.21 | 22.57 | 29.50 | 62.15 | 112.4 | 249.5 | 235.7 | 58.95 | 38.81 | 32.85 |
| | High | 61.77 | 37.60 | 23.93 | 24.73 | 35.80 | 75.13 | 174.5 | 196.4 | 185.9 | 75.11 | 39.99 | 31.97 |
| Niobrara River abv Box Butte (UNW Zone 3) | Historical | 73.22 | 41.04 | 24.37 | 33.22 | 38.45 | 74.53 | 167.6 | 238.9 | 226.9 | 93.11 | 68.49 | 67.81 |
| | Low | 64.81 | 45.25 | 31.03 | 43.00 | 46.10 | 71.48 | 166.8 | 257.8 | 192.8 | 84.62 | 60.72 | 44.75 |
| | Central Tendency | 61.43 | 39.95 | 27.02 | 31.36 | 40.14 | 87.12 | 156.7 | 363.2 | 338.5 | 93.89 | 61.41 | 51.66 |
| | High | 91.55 | 57.42 | 33.84 | 35.02 | 49.58 | 107.8 | 244.0 | 284.2 | 274.9 | 117.9 | 64.08 | 49.07 |
| Niobrara River at Hay Springs (UNW Zone 4) | Historical | 99.05 | 56.34 | 33.25 | 44.33 | 52.34 | 99.88 | 221.3 | 325.2 | 315.0 | 143.2 | 103.5 | 96.82 |
| | Low | 89.42 | 63.37 | 43.02 | 56.24 | 61.41 | 93.00 | 219.2 | 347.9 | 266.1 | 129.7 | 90.95 | 63.90 |
| | Central Tendency | 81.41 | 54.50 | 36.70 | 41.80 | 53.13 | 114.1 | 206.3 | 487.8 | 453.3 | 146.4 | 93.36 | 76.73 |
| | High | 128.3 | 80.79 | 46.56 | 47.00 | 65.50 | 144.0 | 323.0 | 388.3 | 379.7 | 181.4 | 96.70 | 70.55 |
| Niobrara River near Gordon (UNW Zone 5) | Historical | 223.7 | 131.7 | 74.56 | 97.19 | 120.3 | 217.2 | 480.4 | 747.9 | 783.6 | 405.0 | 279.7 | 248.9 |
| | Low | 203.4 | 151.5 | 98.36 | 119.8 | 137.3 | 189.6 | 471.7 | 780.8 | 645.3 | 369.3 | 240.2 | 164.2 |
| | Central Tendency | 180.4 | 128.0 | 81.38 | 91.11 | 119.1 | 240.9 | 445.9 | 1097 | 1070 | 419.3 | 255.1 | 217.0 |
| | High | 303.5 | 198.1 | 109.6 | 104.9 | 149.8 | 314.5 | 716.9 | 898.5 | 948.9 | 517.8 | 260.3 | 181.9 |
| Snake River near Burge (CENEB Zone 1) | Historical | 29.72 | 19.27 | 9.13 | 12.41 | 18.18 | 30.94 | 64.36 | 96.39 | 104.6 | 65.06 | 48.34 | 32.60 |
| | Low | 27.97 | 23.43 | 12.58 | 15.96 | 20.02 | 21.59 | 61.72 | 98.25 | 83.38 | 54.82 | 38.06 | 20.40 |
| | Central Tendency | 24.19 | 18.96 | 9.32 | 11.64 | 16.75 | 31.35 | 58.95 | 139.3 | 131.1 | 74.05 | 45.48 | 34.57 |
| | High | 44.06 | 37.46 | 17.19 | 15.48 | 18.89 | 42.95 | 115.8 | 135.8 | 135.8 | 90.17 | 49.10 | 23.55 |
| Niobrara River near Sparks (CENEB Zone 2) | Historical | 431.1 | 272.8 | 139.5 | 179.7 | 237.0 | 427.1 | 923.0 | 1394 | 1534 | 849.8 | 614.5 | 470.1 |
| | Low | 397.3 | 316.5 | 184.9 | 227.6 | 266.7 | 332.5 | 887.1 | 1420 | 1252 | 734.0 | 506.0 | 305.0 |
| | Central Tendency | 351.3 | 263.5 | 146.9 | 170.0 | 226.8 | 450.7 | 851.6 | 2015 | 2046 | 946.5 | 574.7 | 447.5 |
| | High | 606.5 | 453.8 | 233.7 | 211.0 | 268.3 | 604.0 | 1530 | 1872 | 1946 | 1145 | 623.9 | 345.7 |
| Niobrara River near Spencer (CENEB Zone 3) | Historical | 783.4 | 499.6 | 262.8 | 311.5 | 397.4 | 826.2 | 1702 | 2444 | 2725 | 1497 | 1040 | 864.1 |
| | Low | 731.4 | 577.8 | 330.2 | 395.3 | 445.9 | 591.1 | 1471 | 2349 | 2167 | 1150 | 794.6 | 588.0 |
| | Central Tendency | 666.7 | 492.0 | 274.3 | 311.9 | 402.0 | 839.4 | 1550 | 3324 | 3574 | 1856 | 1011 | 916.9 |
| | High | 1126 | 964.8 | 482.8 | 407.7 | 449.7 | 1260 | 3548 | 3766 | 3863 | 2203 | 1130 | 645.41 |

**Table 9.—Historical (1960-2010) and Projected Changes (Percent) in Unimpaired (Natural) Streamflow Based on VIC Model Simulations for Three Future Scenarios (2050s compared with historical)**

| Variable | Scenario | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Niobrara River at Stateline (UNW Zone 1) | Historical | 27.25 | 15.28 | 10.13 | 14.47 | 16.74 | 30.07 | 68.24 | 83.25 | 75.69 | 30.76 | 21.85 | 23.11 |
| | Low | -11% | 9.3% | 28% | 33% | 24% | 2.9% | 1.2% | 12% | -13% | -7.3% | -5.9% | -33% |
| | Central Tendency | -13% | 0.2% | 12% | -4.1% | 11% | 21% | -4.1% | 58% | 64% | -0.4% | -11% | -28% |
| | High | 18% | 34% | 37% | 3% | 30% | 41% | 48% | 28% | 25% | 27% | -8.7% | -28% |
| Niobrara River at Agate (UNW Zone 2) | Historical | 50.66 | 27.56 | 17.25 | 23.73 | 27.74 | 52.29 | 119.1 | 160.3 | 150.8 | 59.28 | 43.49 | 44.65 |
| | Low | -12% | 8.9% | 28% | 31% | 22% | -0.6% | 0.6% | 10% | -14% | -8.2% | -9.3% | -34% |
| | Central Tendency | -14% | -1.4% | 11% | -4.9% | 6.4% | 19% | -5.7% | 56% | 56% | -0.5% | -11% | -26% |
| | High | 22% | 36% | 39% | 4% | 29% | 44% | 46% | 22% | 23% | 27% | -8.0% | -28% |
| Niobrara River abv Box Butte (UNW Zone 3) | Historical | 73.22 | 41.04 | 24.37 | 33.22 | 38.45 | 74.53 | 167.6 | 238.9 | 226.9 | 93.11 | 68.49 | 67.81 |
| | Low | -11% | 10% | 27% | 29% | 20% | -4.1% | -0.5% | 7.9% | -15% | -9.1% | -11% | -34% |
| | Central Tendency | -16% | -2.7% | 11% | -5.6% | 4.4% | 17% | -6.5% | 52% | 49% | 0.8% | -10% | -24% |
| | High | 25% | 40% | 39% | 5% | 29% | 45% | 46% | 19% | 21% | 27% | -6.4% | -28% |
| Niobrara River at Hay Springs (UNW Zone 4) | Historical | 99.05 | 56.34 | 33.25 | 44.33 | 52.34 | 99.88 | 221.3 | 325.2 | 315.0 | 143.2 | 103.5 | 96.82 |
| | Low | -10% | 12% | 29% | 27% | 17% | -6.9% | -0.9% | 7.0% | -16% | -9.4% | -12% | -34% |
| | Central Tendency | -18% | -3.3% | 10% | -5.7% | 1.5% | 14% | -6.8% | 50% | 44% | 2.2% | -10% | -21% |
| | High | 29% | 43% | 40% | 6.0% | 25% | 44% | 46% | 19% | 21% | 27% | -6.6% | -27% |
| Niobrara River near Gordon (UNW Zone 5) | Historical | 223.7 | 131.7 | 74.56 | 97.19 | 120.3 | 217.2 | 480.4 | 747.9 | 783.6 | 405.0 | 279.7 | 248.9 |
| | Low | -9.1% | 15% | 32% | 23% | 14% | -13% | -1.8% | 4.4% | -18% | -9% | -14% | -34% |
| | Central Tendency | -19% | -2.8% | 9.1% | -6.2% | -0.9% | 11% | -7.2% | 47% | 37% | 3.5% | -8.8% | -13% |
| | High | 36% | 50% | 47% | 8.0% | 25% | 45% | 49% | 20% | 21% | 28% | -6.9% | -27% |
| Snake River near Burge (CENEB Zone 1) | Historical | 29.72 | 19.27 | 9.13 | 12.41 | 18.18 | 30.94 | 64.36 | 96.39 | 104.6 | 65.06 | 48.34 | 32.60 |
| | Low | -5.9% | 22% | 38% | 29% | 10% | -30% | -4.1% | 1.9% | -20% | -16% | -21% | -37% |
| | Central Tendency | -19% | -1.6% | 2.1% | -6.2% | -7.8% | 1.3% | -8.4% | 44% | 25% | 14% | -5.9% | 6.1% |
| | High | 48% | 94% | 88% | 25% | 3.9% | 39% | 80% | 41% | 30% | 39% | 1.6% | -28% |
| Niobrara River near Sparks (CENEB Zone 2) | Historical | 431.1 | 272.8 | 139.5 | 179.7 | 237.0 | 427.1 | 923.0 | 1394 | 1534 | 849.8 | 614.5 | 470.1 |
| | Low | -7.8% | 16% | 33% | 27% | 13% | -22% | -3.9% | 1.8% | -18% | -14% | -18% | -35% |
| | Central Tendency | -18% | -3.4% | 5.3% | -5.4% | -4.3% | 5.5% | -7.7% | 45% | 33% | 11% | -6.5% | -4.8% |
| | High | 41% | 66% | 67% | 17% | 13% | 41% | 66% | 34% | 27% | 35% | 2% | -26% |
| Niobrara River near Spencer (CENEB Zone 3) | Historical | 783.4 | 499.6 | 262.8 | 311.5 | 397.4 | 826.2 | 1702 | 2444 | 2725 | 1497 | 1040 | 864.1 |
| | Low | -6.6% | 16% | 26% | 27% | 12% | -28% | -14% | -3.9% | -20% | -23% | -24% | -32% |
| | Central Tendency | -15% | -1.5% | 4.4% | 0.1% | 1.1% | 1.6% | -8.9% | 36% | 31% | 24% | -2.8% | 6.1% |
| | High | 44% | 93% | 84% | 31% | 13% | 52% | 108% | 54% | 42% | 47% | 8.7% | -25% |

# IV. Linkages of Climate Change Scenarios and Basin Study Models

This section describes how the historical and projected future climate change scenario data described in this technical report informs other analyses in the Basin Study. The data described here informs the study in the following ways:

1. Developing historical and projected future climate inputs for the watershed models for both UNW and CENEB portions of the study area
2. Developing projected losses due to evaporation from Box Butte and Merritt Reservoirs
3. Developing water supply inputs to the CENEB surface water operations model
4. Developing inputs to the economic benefits analysis

The modeling framework for the Basin Study consists of two modeled subregions, namely the UNW portion and the CENEB portion (see illustrations of these modeled areas in figure 1). For each of the subregions (UNW and CENEB), a series of models have been developed to simulate the full water balance of the region, including soil water dynamics of agricultural areas, and surface and groundwater hydrology. This information is used as input to develop integrated models (one for each subregion) which simulate managed flows in the Niobrara River and major tributaries. The model component interactions are illustrated in figure 17, which suggests a cyclical pattern without an endpoint. The following paragraph briefly describes the model interactions to provide context for how the datasets developed here fit into the overall modeling framework. The UNW and CENEB integrated models generally have the same components, although they differ somewhat with respect to the tools employed. Detailed descriptions of the modeling framework and specific components are provided in Appendix F, the integrated water management modeling report.

Climate data (historical or projected future scenarios) at select stations are used as input to the watershed model. The other input to the watershed model is available surface water supplies for irrigation. The model simulates water requirements for modeled crops and identifies on a monthly basis the amount of groundwater needed to meet total irrigation demand, the amount of applied water resulting in groundwater recharge, and surface runoff to streams. There exist unique watershed models for the UNW and CENEB subregions of the study area.

The model interactions for the UNW subregion are first described, followed by the model interactions for the CENEB subregion. The watershed model, groundwater model, and surface water operations model were linked to form the integrated model which is designed to be a dynamic representation of the total

water budget for the Niobrara River (Stateline to Gordon). Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and transfers. Information generated in one model can be used as input to another model. The primary information exchanges are listed below:

- Water diversions in the surface water model and well pumping in the groundwater model are taken from outputs of the watershed model.
- Recharge to the groundwater model is taken from the watershed model for deep percolation from the land, and from the surface water model for canal seepage. The stream routing in the groundwater model requires inputs from the surface water model.
- The surface water model gains runoff as calculated by the watershed model, and baseflow as calculated by the groundwater model. It can lose water to channel seepage if the river stage is higher than the water table.

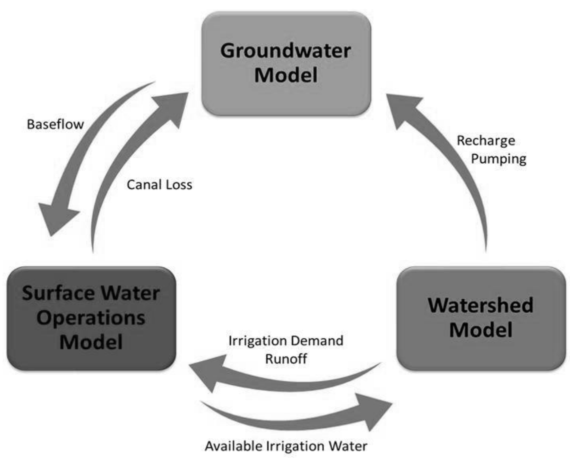



**Figure 17.—Model interactions for the UNW subregion of the study area. Figure developed by Nebraska Department of Natural Resources.**

Because the amount of available water for the diversions may differ from initial assumptions made by the watershed model in its first iteration, a second iteration of the model is performed to incorporate the revised amount of delivered surface water to crops. Following the second iteration of the UNW watershed model, second iterations of the groundwater model and surface water operations model are also performed to achieve closure in the modeling process. Achieving closure means total streamflow in the surface water operations model differs by less than 10 percent between model iterations. It is assumed that two iterations of the model flow are sufficient to achieve closure of results. Further details of the

sequence of the individual model simulations and the data transfers to achieve an integrated simulation are provided in Appendix F, the integrated model technical report.

The CENEB subregion of the study area has similar model interactions. However, a more simple representation of surface water operations comprises the CENEB surface water operations model. A simpler model is used because the alternatives considered as part of the Basin Study to reduce water supply and demand gaps are focused on the UNW subregion and it has been determined through previous studies that the CENEB subregion is hydrologically disconnected from the UNW subregion. Analysis supporting the selection of this approach is provided in Appendix B, the groundwater modeling report. In addition, due to the simple configuration of the CENEB surface water operations model, only one iteration of the models is performed.

## A. Inputs to Watershed Models

This section describes inputs to the UNW and CENEB subregion watershed models developed by Reclamation's Technical Service Center. It should be noted that, although Reclamation provided inputs to the models, the models were implemented by Nebraska DNR and its contractors. The watershed models for the UNW and CENEB subregions of the study area ingest daily precipitation, daily minimum and maximum air temperature, and daily reference e ET at select climate stations. Historical climate inputs have previously been developed by Nebraska DNR and its contractors, which include data at NWS/Co-Op climate stations illustrated in figure 18 and tabulated in table 10 (data source: High Plains Regional Climate Center). Among those stations used for both UNW and CENEB subregions collectively, five stations have portions of the historical simulation period from 1960-2010 during which no measurements were taken (ALBI, ARNO, TRYO, WAHO, and YORK). Therefore, a filling technique was developed and implemented to fill records at these stations for the Basin Study simulations. The approach for data filling is described below.

### 1. Filling Years with No Measurement Data

For minimum and maximum temperature, the three stations closest to each NWS/Co-Op station with periods of no measurement are identified as anchor stations. The station with periods of no measurement may be referred to as the index station. Correlations in daily minimum and maximum temperature were computed between anchor stations and corresponding index station to confirm inclusion of three closest stations for filling of records at the index station.

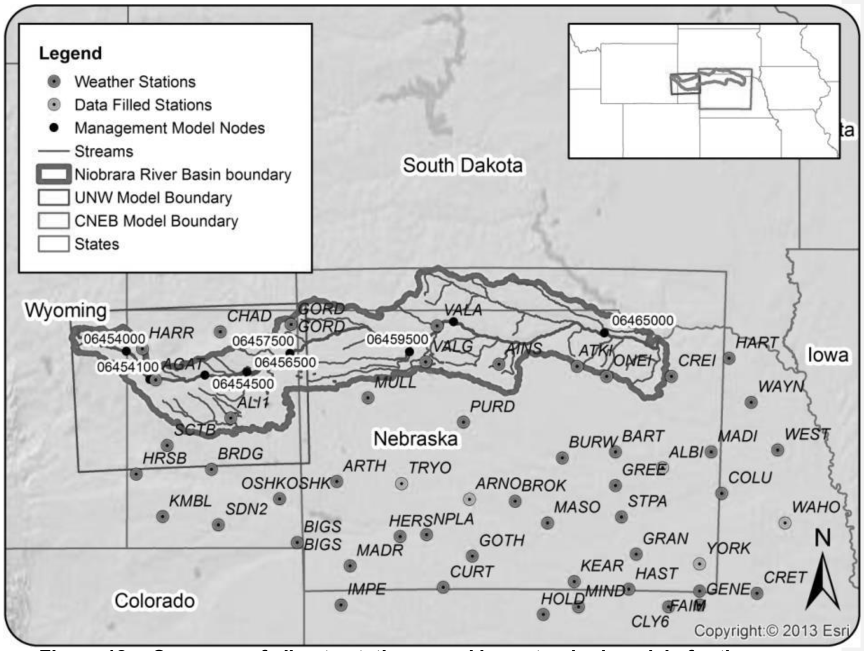



**Figure 18.—Summary of climate stations used by watershed models for the Niobrara River Basin Study.**

Correlations exceed 90 percent for all pairs of stations evaluated. Then, for each missing Julian day at the index station, the percentile of temperature (minimum or maximum) for that Julian day at each anchor station is computed based on the distribution of temperature on that Julian day for each year of the 1960-2010 period. Then for each missing day, the median percentile of the three anchor stations is used to determine the actual missing day temperature (minimum or maximum) based on the distribution of the Julian day temperature over the 1960-2010 period at the index station.

For precipitation, a procedure similar to that described for temperature is used to fill periods of no measurement. However, due to the fact that precipitation events may be localized and not experienced in the same way at all three anchor stations, a single anchor station was used for data filling. The anchor station was selected objectively as one of the three closest stations with the highest correlation with the index station.

**Table 10.—Summary of NWS/Co-Op Stations Used as Input to Watershed Models (UNW and CENEB Subregions Included)**

Sites highlighted in gray have portions of the historical simulation period (1960–2010) with no measurements.

| Station | Code | Latitude | Longitude | Station | Code | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| AGATE_3_E | AGAT | 42.42 | –103.73 | HAST | HAST | 40.65 | –98.38 |
| AINS | AINS | 42.55 | –99.85 | HERS | HERS | 41.10 | –100.97 |
| ALBI | ALBI | 41.68 | –98.00 | HOLD | HOLD | 40.43 | –99.35 |
| ALLIANCE_1_WNW | ALI1 | 42.10 | –102.88 | HARRISBURG_12_WNW | HRSB | 41.63 | –103.95 |
| ARNO | ARNO | 41.42 | –100.18 | IMPE | IMPE | 40.52 | –101.63 |
| ARTH | ARTH | 41.57 | –101.68 | KEAR | KEAR | 40.72 | –99.00 |
| ATKI | ATKI | 42.53 | –98.97 | KIMBALL | KMBL | 41.27 | –103.65 |
| BART | BART | 41.82 | –98.53 | MADI | MADI | 41.82 | –97.45 |
| BIG_SPRINGS | BIGS | 41.05 | –102.13 | MADR | MADR | 40.85 | –101.53 |
| BRIDGEPORT | BRDG | 41.67 | –103.10 | MASO | MASO | 41.22 | –99.30 |
| BROK | BROK | 41.40 | –99.67 | MIND | MIND | 40.50 | –98.95 |
| BURW | BURW | 41.77 | –99.13 | MULL | MULL | 42.27 | –101.33 |
| CHADRON_1_NW | CHAD | 42.82 | –103.00 | NPLA | NPLA | 41.12 | –100.67 |
| CLY6 | CLY6 | 40.50 | –97.93 | ONEI | ONEI | 42.45 | –98.63 |
| COLU | COLU | 41.47 | –97.33 | OSHKOSH | OSHK | 41.42 | –102.33 |
| CREI | CREI | 42.45 | –97.90 | PURD | PURD | 42.07 | –100.25 |
| CRET | CRET | 40.62 | –96.93 | SCOTTSBLUFF_AP | SCTB | 41.87 | –103.60 |
| CURT | CURT | 40.67 | –100.48 | SIDNEY_6_NNW | SDN2 | 41.20 | –103.02 |
| FAIM | FAIM | 40.63 | –97.58 | STPA | STPA | 41.27 | –98.47 |
| GENE | GENE | 40.52 | –97.58 | TRYO | TRYO | 41.55 | –100.95 |
| GORDON_6_N | GORD | 42.88 | –102.20 | VALENTINE_WSO_AP | VALA | 42.87 | –100.55 |
| GOTH | GOTH | 40.93 | –100.15 | VALG | VALG | 42.57 | –100.68 |
| GRAN | GRAN | 40.95 | –98.30 | WAHO | WAHO | 41.22 | –96.62 |
| GREE | GREE | 41.53 | –98.53 | WAYN | WAYN | 42.23 | –97.00 |
| HARRISON | HARR | 42.68 | –103.88 | WEST | WEST | 41.83 | –96.70 |
| HART | HART | 42.60 | –97.25 | YORK | YORK | 40.87 | –97.58 |

Notes: ALBI no measurement years are 2008–2010; ARNO no measurement years are 2008–2010; TRO no measurement years are 2008–2010; WAHO no measurement years are 2004–2010; YORK no measurement years are 2008–2010.

For reference ET, a procedure similar to that described for temperature and precipitation is used to fill periods where underlying climate data to compute ET are not available. However, due to the fact that timeseries of observed referent ET do not exist at each NWS/Co-Op station, historical simulations of a dual crop coefficient Penman Monteith ET model (further described below in Section IV.A.2) at corresponding locations were used as anchor stations and thus used for data filling. The complete datasets, resulting from the data-filling procedures described above, are used as input to the watershed models (UNW and CENEB subregions) to develop the Baseline No Action scenario for the Basin Study.

## 2. Deriving Future Scenario Inputs for Watershed Models (UNW and CENEB)

***Precipitation and Temperature***
As described previously, the watershed models use individual station data as input rather than gridded datasets, such as those used in development of climate change scenarios. Climate change scenarios were developed on a grid basis, where each grid cell is 1/8 degree square in size. In order to develop station-based future scenario inputs for the watershed models, we use the grid based historical and future scenario data to derive the future station-based data. The approach is described in detail below.

Historical and GCM projection gridded meteorological data (daily precipitation, minimum and maximum temperature) are used as the basis for deriving future scenario inputs at each NWS/Co-Op station. For each month January through December, cumulative distribution functions (CDFs) of the GCM projection data are computed over the 2030-2059 future time horizon for each selected climate change scenario (refer to table 4). CDFs are also computed from the historical gridded data over the historical period 1970-1999. A change can be computed between the future scenario and historical period at each percentile of the CDFs. That change represents the projected climate change for that scenario for that month at each percentile. The historical NWS/Co-Op station data can then be adjusted based on the look up table of projected change at a given percentile. As a result, projected climate data are computed for each station and for each of the three climate change scenarios (Low, Central Tendency, and High). These data are used as the scenario inputs to the watershed models (UNW and CENEB subregions). This process may be qualitatively illustrated using figure 19.

***Reference Evapotranspiration***
The watershed models ingest daily reference ET at NWS/Co-Op station locations (calculated using a modified Hargreaves-Samani approach; further described in Appendix E, the watershed modeling report), in addition to precipitation, and minimum and maximum air temperature. In a procedure similar to that used to develop future scenario inputs of precipitation and temperature, a mapping approach is used to adjust historical station-based reference ET for the watershed models based on projected changes in ET computed using historical and future

simulations of a dual crop coefficient Penman Monteith ET model. Current and future ET estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2015).

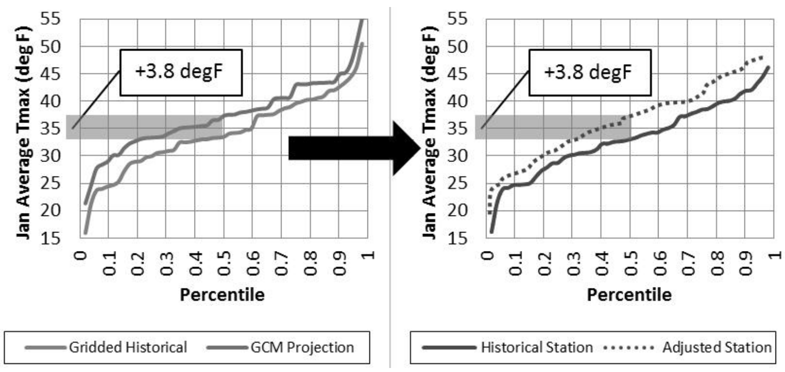



**Figure 19.—Example of percentile adjustments for development of station-based Future No Action maximum temperature data for input to watershed model. Fabricated data were used in development of the figure.**

The ET Demands model is based on the Penman Monteith dual crop coefficient method, as described in the Food and Agriculture Organization (FAO) of the United Nations, Irrigation and Drainage Paper 56 (Allen et. al, 1998). The Environmental and Water Resources Institute of the American Society of Civil Engineers (ASCE-EWRI) has adopted the FAO-56 Penman Monteith equation as the standardized equation for calculating reference ET (ASCE-EWRI, 2005). The short grass reference crop version of the Penman Montieth equation was used to be consistent with previous Reclamation work. It should be noted that, in contrast, a tall-crop reference ET is used in the watershed models.

The ET Demands model described above was employed using historical gridded meteorological data consistent with VIC hydrologic model simulations (described earlier in this technical report) and climate change scenario development. The model was run for each grid cell data coinciding with individual NWS/Co-Op station locations. The model was employed for the same grid cells for both the Baseline No Action and Future No Action scenarios (including low, central tendency, and high). Simulated reference ET from historical and future scenario model runs were saved and used as a basis for developing future scenario reference ET for the watershed models.

Similar to the approach taken to develop scenario precipitation and temperature inputs, CDFs of reference ET were computed for each month for simulated historical and projected conditions. Changes (percent) between future and

historical referent ET were computed for each percentile. The historical reference ET at each NWS/Co-Op station was then adjusted by computed changes at each percentile to derive future reference ET at the same NWS/Co-Op stations. The adjusted precipitation, minimum and maximum air temperature, and reference ET were then used as input for Future No Action simulations of the watershed models (UNW and CENEB subregions).

## B. Losses from Reservoir Evaporation

Net evaporation rates for Box Butte and Merritt reservoirs in the Niobrara River Basin were calculated using available data in combination with results from the Complementary Relationship Lake Evaporation (CRLE) model (Morton et al., 1985). Net evaporation rates for historical and future scenarios were developed as inputs to the UNW and CENEB surface water operations models. It should be noted that although Reclamation's Technical Service Center provided these inputs, it did not implement the integrated models.

CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimate monthly evaporation. Net evaporation may be calculated as evaporation minus precipitation (evaporation – precipitation) at each timestep. This model had been previously used as part of Reclamation's WWCRA to estimate evaporative losses in 12 major reservoirs across the Western U.S. The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for the major reservoirs of the Western U.S.

The CRLE model calculates evaporation for each reservoir based on average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the historical analysis period (1960-2010). Air temperature and precipitation for the VIC model grid cells that coincide with each of the two reservoirs were used as the air temperature and precipitation inputs to the model. Additional inputs, namely dewpoint depression, function parameters, and salinity were derived through various approaches described below.

As part of Reclamation's WWCRA water demands assessment (2015), monthly dewpoint depression was developed for each 8-digit Hydrologic Unit Code subbasin (HUC8 subbasin) in the Western U.S. Dewpoint depression values for the HUC8 subbasins that encompass the two reservoirs were used as inputs to the CRLE model.

The CRLE model derives solar radiation using the approach of Thornton and Running (1999), in which a parametric equation derives solar radiation based on the difference between daily maximum and minimum temperature. Three required function parameters to compute solar radiation were calibrated at the HUC8 subbasin level as part of Reclamation's WWCRA (2015). Similar to the monthly dewpoint depression values, calibrated solar radiation function

parameters at the HUC8 subbasin scale were used directly as input to the CRLE model for corresponding locations. Finally, average reservoir salinity was taken from a study by Bennett et al. (2007) in which they reported on salinity levels in various reservoirs in Nebraska. A value of 310 ppm was used for both Box Butte and Merritt Reservoirs.

It should be noted that for Box Butte Reservoir, historical net evaporation had previously been developed and used in the calibration of the UNW surface water operations model. As such, the historical net evaporation data were used for the Baseline No Action scenario. For the Future No Action scenarios (Low, Central Tendency, and High) a mapping technique, similar to that described above for development of perturbed watershed model inputs (refer to section 4.1.2), was applied to develop adjusted net evaporation at Box Butte based on computed changes between CRLE model future and historical simulations. For Merritt Reservoir, monthly pan evaporation data from 1970-2013 was available and evaluated. However, comparisons of these data with CRLE model outputs suggest that the pan evaporation data are not representative of actual reservoir evaporation. Therefore, for the purpose of the Basin Study, CRLE model outputs of net evaporation were used directly in the CENEB subregion surface water operations model for the Baseline No Action and Future No Action scenarios.

Figure 20 illustrates the distribution of Baseline No Action and Future No Action scenario (Low, Cental Tendency, and High) net evaporation at Box Butte (left) and Merritt Reservoirs (right) based on the above described assumptions and model inputs. The thick black line represents the median annual net evaporation across all simulated years, while the lower end of the box and upper end of the box represent the 25$^{th}$ and 75$^{th}$ percentile values, respectively. The lower and upper whiskers represent the 10$^{th}$ and 90$^{th}$ percentile values across all simulated years.

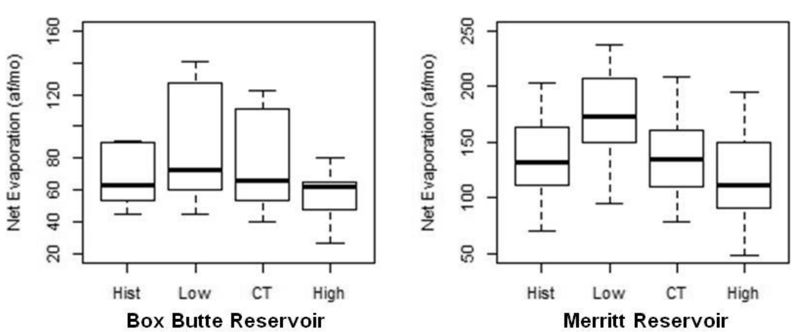



**Figure 20.—Distributions of historical (1960-2010) and projected net evaporation at Box Butte and Merritt Reservoirs for Low, Central Tendency, and High scenarios representing a 2030–2059 future time horizon.**

According to model simulations and subsequent adjustments to Box Butte net evaporation based on observed data, Box Butte Reservoir has lower net evaporation than Merritt Reservoir, with a historical median (over 1960-2010) of about 63 inches. Merritt Reservoir has a median net evaporation of about 132 inches computed over the same years. The primary difference in net evaporation between the two reservoirs may relate to the existing historical net evaporation data for Box Butte Reservoir. Comparisons of strictly CRLE modeled net evaporation between the two reservoirs yield values much closer in magnitude.

Generally for Box Butte, the Low scenario indicates a range from a small decrease to more substantial increase in net evaporation across all scenarios for the future time horizon 2030-2059, with the median being an increase of about 15 percent. The High scenario indicates a range from a more substantial decrease in net evaporation to a modest increase in net evaporation, with the median being a decrease of about 2 percent. The Central Tendency scenario indicates a median increase of about 6 percent. For Merritt, the Low scenario indicates a median increase of about 32 percent, while the High scenario indicates a median decrease of about 15 percent and the Central Tendency indicates a median increase of about 2 percent.

**Table 11.—Distributions of historical (1960–2010) and projected net evaporation at Box Butte and Merritt Reservoirs for Low, Central Tendency, and High scenarios representing a 2030–2059 future time horizon**

| Quantile | Hist (af/mo) | Low (af/mo) | CT (af/mo) | High (af/mo) |
|---|---|---|---|---|
| **Box Butte Reservoir** | | | | |
| 10th | 44.64 | 44.51 | 39.54 | 26.45 |
| 25th | 53.54 | 60.54 | 53.36 | 47.39 |
| 50th | 62.77 | 72.39 | 66.36 | 61.69 |
| 75th | 89.79 | 127.7 | 111.2 | 65.30 |
| 90th | 91.00 | 140.6 | 122.4 | 80.02 |
| **Merritt Reservoir** | | | | |
| 10th | 70.17 | 94.75 | 78.19 | 48.38 |
| 25th | 111.2 | 150.3 | 110.0 | 90.43 |
| 50th | 131.7 | 173.8 | 134.9 | 111.7 |
| 75th | 163.7 | 207.6 | 161.4 | 150.3 |
| 90th | 202.9 | 237.0 | 208.8 | 194.8 |

## C. Additional Inputs to CENEB Surface Water Operations Model

This technical report describes the approach for development of adjusted inputs to the CENEB surface water operations model. Appendix D, the CENEB surface water operations modeling report, describes the model in more detail and summarizes model results for the Baseline No Action and Future No Action scenarios. This technical report summarizes data development by Reclamation's Technical Service Center to support the CENEB surface water operations modeling effort. It should be noted that Reclamation's Technical Service Center assisted in development of model inputs, but did not implement the model for the Basin Study.

It should be noted that Future with Alternative scenarios (referred to as FA1 and FA2 in corresponding technical reports for the Basin Study) were assumed not to impact the CENEB subregion due to the understanding that the UNW and CENEB subregions are hydrologically disconnected. In other words, alternatives explored in the UNW subregion were assumed not to impact hydrology in the CENEB subregion.

Development of Merritt Reservoir net evaporation for the CENEB surface water operations model was described in detail in Section 4.2. Additional inputs to this model include surface runoff, groundwater baseflows, groundwater pumping, and crop water demands. As previously mentioned, surface runoff, groundwater pumping, and crop water demands result from CENEB watershed model simulations. Groundwater baseflows result from CENEB groundwater model simulations.

CENEB watershed and groundwater model simulations were available for Baseline No Action and Future No Action scenarios. Due to Basin Study time constraints, a historical simulation for each model was not performed. However, it was assumed that Baseline No Action results represent historical conditions, with the following justification. The Baseline No Action scenario is comprised of historical climate inputs and current farming and management practices. Current land use was assumed to be crop patterns and acreage from 2010. The historical condition differs in that historical annual land use would have been used. Analysis of historical crop acreage by county and crop type within the Niobrara River Basin provides justification that historical land use has not varied substantially from year to year since 1940. Table 12 summarizes mean crop acreage by county within the Niobrara River Basin, along with the standard deviation and variance. Variability around the mean acreage is small compared with the total crop acreage, which suggests little sensitivity of model results to the assumption that 2010 cropping patterns are representative of historical conditions. It should be noted that, in addition to changes in land use and water management, changes in farming practices and technology have also influenced water supply and demand; however, these practices were held constant for all model simulations.

**Table 12.—Summary of Historical Crop Acreage by County (statistics computed over 1940–2010)**

| County | Crop Acreage Annual Mean | Crop Acreage Standard Deviation | Crop Acreage Variance |
|---|---|---|---|
| Bennett | na | na | na |
| Boyd | 328,669 | 535 | 286,529 |
| Brown | 771,749 | 363 | 131,449 |
| Cherry | 3,955,259 | 219 | 48,145 |
| Gregory | na | na | na |
| Holt | 1,550,257 | 746 | 556,659 |
| Keya Paha | 499,148 | 212 | 45,053 |
| Rock | 651,432 | 278 | 77,049 |
| Sherman | 366,187 | 386 | 149,233 |
| Todd | na | na | na |
| Tripp | na | na | na |

The CENEB surface water operations model was calibrated over the historical period to USGS measured streamflows at three locations:

- ID 06461500 Niobrara River near Sparks, Nebraska
- ID 06459500 Snake River near Burge, Nebraska
- ID 06465000 Niobrara River near Spencer, Nebraska

Reclamation's Technical Service Center developed adjusted historical Merritt Reservoir inflows for the purpose of calibrating the CENEB surface water operations model, as well as adjusted Merritt Reservoir inflows for the Future No Action scenarios. Other model inputs were provided by Nebraska DNR and its contractors.

Historical inflows to Merritt Reservoir were computed by Reclamation's Nebraska-Kansas Area Office for the period 1967-2013. These inflows were assumed to be observed historical inflows. These inflows were compared with modeled historical inflows computed as the sum of CENEB groundwater model baseflow and CENEB watershed model surface runoff for the same period. As a way of calibrating the modeled inflows to more closely match the "observed" inflows (computed by Reclamation), modeled historical inflows were adjusted such that the mean and distribution of modeled inflows was comparable with observed inflows. The same mapping procedure described in Section 4.1.2 for development of adjusted climate scenarios was used to adjust modeled inflows at Merritt to better match observed inflows. As described in Section 4.1.2, a unique map was developed for each month, relating the CDF of modeled inflows with the CDF of observed inflows. The same monthly maps were also used to adjust Future No Action scenario inflows. Additional details regarding the approach for CENEB surface water operations model simulations and summarized results are provided in Appendix D.

## D. Inputs to Economic Benefits Analysis

The economic benefits analysis performed as part of the Basin Study is comprised of two parts: recreation benefits and agricultural benefits at Mirage Flats Irrigation District in the UNW subregion. This section describes inputs developed by Reclamation's Technical Service Center in support of the economic benefits analysis. Details of the economic benefits analysis may be found in Appendix G, the economic benefits analysis report.

Inputs to the recreation benefits analysis include monthly average air temperature and end of month water levels at Box Butte and Merritt reservoirs, and monthly streamflow in the Niobrara Wild and Scenic River at Sparks, Nebraska. NWS/Co-Op stations that are closest to Box Butte and Merritt reservoirs were used as the basis for historical monthly average temperature data. The NWS/Co-Op station closest to Box Butte reservoir is ALLIANCE_1_WNW. The closest NWS/Co-Op station to Merritt Reservoir is VALENTINE_WSO_AP. Refer to figure 18 and table 9 for additional information about these stations and their geographic locations. Historical monthly average temperatures at the two stations were used for the Baseline No Action scenario. Future No Action scenario monthly average temperatures, developed for input to the UNW and CENEB watershed models, are used for the Future No Action scenarios in the recreation benefits analysis. Merritt and Box Butte reservoir elevations and monthly streamflow at Niobrara River at Sparks for the Baseline No Action and Future No Action scenarios result from the CENEB surface water operations model.

The agricultural benefits analysis at Mirage Flats Irrigation District requires monthly field deliveries, monthly pumping depths and pumping rates for each crop. These values result from the UNW watershed model. Reclamation's Technical Service Center was not directly involved in developing these values.

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# V. Summary

The climate change analysis report for the Niobrara River Basin Study summarizes historical and projected future climate and water supply for the Niobrara River Basin and discusses the development of climate and hydrologic inputs for various modeling components of the Basin Study. This analysis uses historical and projected future climate information consistent with Reclamation's WWCRA. It also uses simulated historical and projected future hydrology based on the VIC hydrologic model. Although hydrologic inputs to other Basin Study modeling components were primarily developed using a watershed model described in the Watershed Modeling Report, Appendix E, the simulations described in this report were used to inform those data and to provide an overall assessment of basin wide water supply and demand.

The Niobrara River Basin has a substantial moisture gradient from west to east, with the western portion being semiarid and the eastern portion being more humid. Historical trend analysis over the period 1950-2010 indicates that mean annual temperature has increased by about 0.6°F, precipitation has increased about 12 percent, and mean annual runoff has increase by about 45 percent basin wide. These results are consistent with values reported by other studies of historical climate trends in the region.

For the 2060s future time horizon, the Central Tendency scenario projects warmer and wetter conditions on an annual basis, with greater mean annual precipitation (8 percent), temperature (3°F), and runoff (13 percent). Seasonally though, projected peak streamflows are expected to increase (50 percent in the upper basin and 30 percent in the lower basin), while projected low flows are expected to decrease (by 10 to 20 percent). Additional scenarios, which span a range of projected conditions, indicate a range from slightly drier conditions with modest changes to streamflow, to more substantially wetter conditions than the Central Tendency and increased annual streamflow volumes.

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# VI. Uncertainties

This section summarizes uncertainties associated with various aspects of the Basin Study water supply assessment, including the use of climate change scenarios, as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of GCM climate projections and applied downscaling techniques is provided by Reclamation (2011). The nature of these uncertainties is only briefly described below.

## A. Global Climate Projections, Modeling, and Downscaling

In the Basin Study, select GCM projections were selected that meet established criteria. This procedure is described in detail in Section 3.1. This approach has its strengths and weaknesses in the context of climate change assessment, as do all others.

The climate projections considered in this report represent a range of future climate conditions under the criteria selected for analysis. However, uncertainties associated with the select GCM projections and their assumptions of global growth and land use, are not explored in this analysis. Uncertainties associated with GCMs are further explored below.

GCMs themselves have associated uncertainty with respect to their initial conditions and representation of physical processes. GCM simulations are designed such that they develop their own long timescale climate patterns and these may differ substantially between GCM simulations. Additionally, although GCMs are continually improved to incorporate the current state of science in terms of our understanding of the climate system, they may have biases toward being too wet, too dry, too warm, or too cool. Often, a procedure to remove biases in climate projections relative to a historical baseline is performed which can affect the apparent climate change expressed by the projections (biased versus bias-corrected).

There are also uncertainties associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. As previously mentioned, the Basin Study utilizes statistically downscaled climate projections as a basis for development of future climate scenarios. By selecting single GCM projects to encompass a range of future conditions, the study does not benefit from analysis numerous future climate scenarios that may provide additional context to a climate change impacts assessment.

## B. CMIP3 versus CMIP5 Climate Projections

The Basin Study relies on data and modeling from Reclamation's WWCRA (Reclamation, 2011). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 Western U.S. that fall within Reclamation's management domain. These projections are based on CMIP3 GCM simulations. The next generation of projections, CMIP5 are summarized in IPCC's Fifth Assessment Report, which was completed in 2013. CMIP5 projections reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and GHG emissions. Although CMIP Phase 5 provides the most recently available suite of climate projections to date, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP Phase 3 projections. Current state of practice relies on a range of climate projections for use in impacts studies.

One advantage to using CMIP3 based projections is that numerous existing studies have used CMIP3 based projections and comparisons may be more easily made between results from the Basin Study and other existing studies in the region. In addition, because CMIP3 projections have been used in numerous studies, there is a greater body of knowledge surrounding their use and application.

It should be noted that there are differences in simulated precipitation between CMIP3 based GCMS and CMIP5 based GCMs for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP Phase 3 projections); namely, that these regions will become drier and result in reduced runoff. It is important to recognize that while CMIP Phase 5 offers new information, more work is required to better understand CMIP5 and its differences from CMIP3. In some regions, model resolution is likely the leading factor resulting in differences. In the North American Monsoon region, for example, the higher resolution of CMIP Phase 5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP Phase 3 models.

## C. Historical Meteorological Dataset

Simulations of the historical record by GCMs do not exactly match observations for many reasons. Lack of detailed representation of spatial or topographical features may play a role, as well as simplified representation of physical processes, among others. As mentioned in Section 5.1, a bias correction step is

commonly used to adjust simulated GCM precipitation and temperature to better match observations, by adjusting the statistical distribution of the simulated data to better match those of the observations. The development of statistically downscaled climate projections under Reclamation's WWCRA involved bias correcting GCM simulated precipitation and temperature (daily average) to gridded observations developed by Maurer et al. (2002). The period of bias correction was generally calendar years 1950-1999. Discussion of the bias correction process is provided by Reclamation (2011).

The historical simulation period used as the basis of the Basin Study includes calendar years 1960-2010. The gridded observed historical meteorological dataset by Maurer et al. (2002) was extended by Ed Maurer from 1949-2000 to 1949-2010. Identical methodology was used to develop the extended dataset, as was used to develop the original Maurer et al. (2002) dataset. However, due to the incorporation of 10 years of additional observed station data at many of the stations, and the corresponding filtering of station data based on record length thresholds and total days of available records, the resulting station mix differs slightly between the original dataset and the extended dataset. Therefore, some inconsistency is introduced by using the original Maurer et al. (2002) dataset for bias correction of GCM simulations over the historical period, and using the extended Maurer dataset as the basis of historical simulations and climate change scenario development for the Basin Study.

Comparisons of monthly distributions of total precipitation and average daily temperature illustrate the lack of impact of the identified inconsistency on precipitation and temperature distributions by month. Figures 21 and 22 compare distributions of precipitation and temperature, respectively, using the Maurer et al. (2002) dataset over the period 1950-1999, the extended Maurer dataset over the same period (1950-1999), and the extended Maurer dataset over the period (1950-2010). The figures illustrate the similarity in their distributions by month. The similarity indicates that the use of the extended Maurer dataset for historical simulations and development of climate change scenarios for the Basin Study does not introduce a substantial bias in the results due to the inconsistency of the use of meteorological datasets.

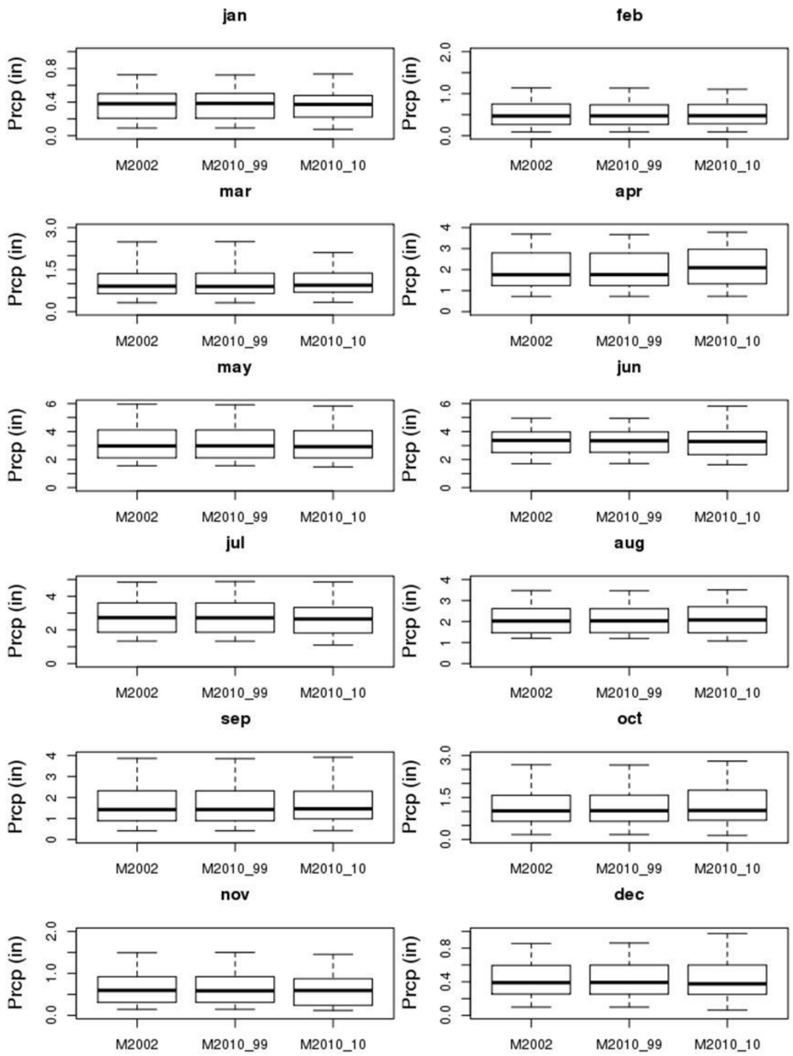


**Figure 21.—Summary of distributions in monthly total precipitation (in) between original Maurer et al. (2002) meteorological dataset and the extended Maurer dataset through 2010.**

- **M2002 represents the Mauer et al. (2002) dataset over years 1950-1999.**
- **M2010_99 represents the extended Maurer dataset over years 1950-1999.**
- **M2020_10 represents the extended Maurer dataset over years 1950-2010.**

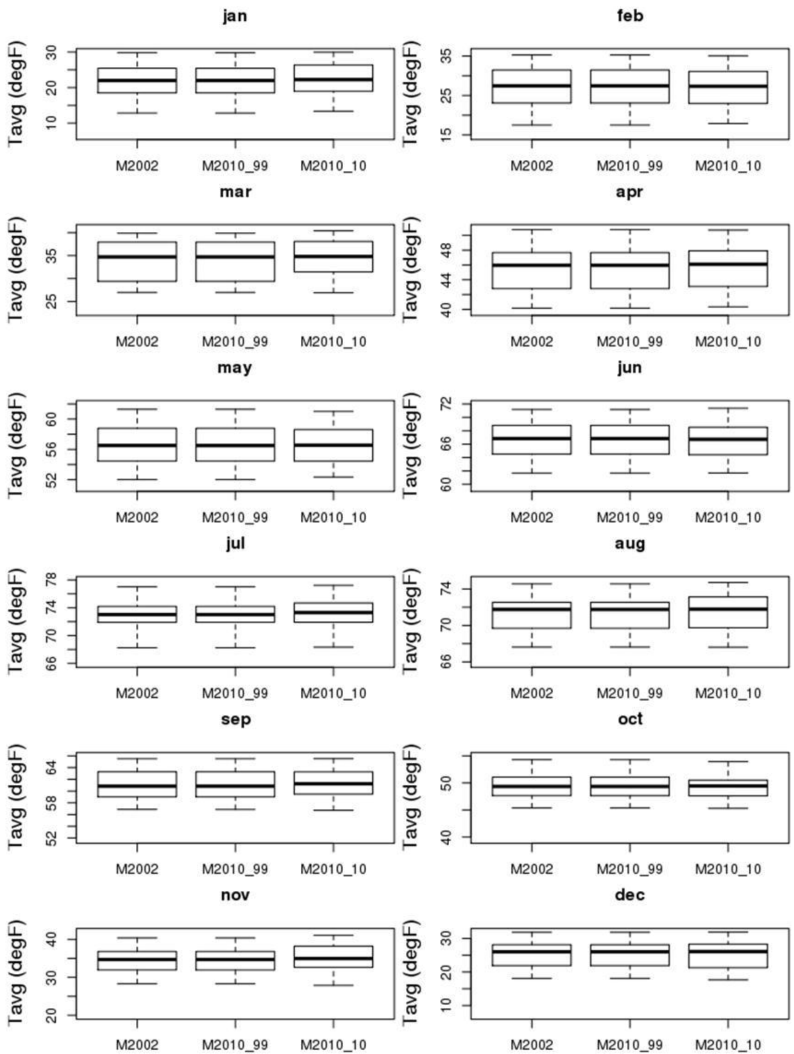


**Figure 22.—Summary of distributions in monthly average temperature (°F) between original Maurer et al. (2002) meteorological dataset and the extended Maurer dataset through 2010.**

- **M2002 represents the Mauer et al. (2002) dataset over years 1950-1999.**
- **M2010_99 represents the extended Maurer dataset over years 1950-1999.**
- **M2020_10 represents the extended Maurer dataset over years 1950-2010.**

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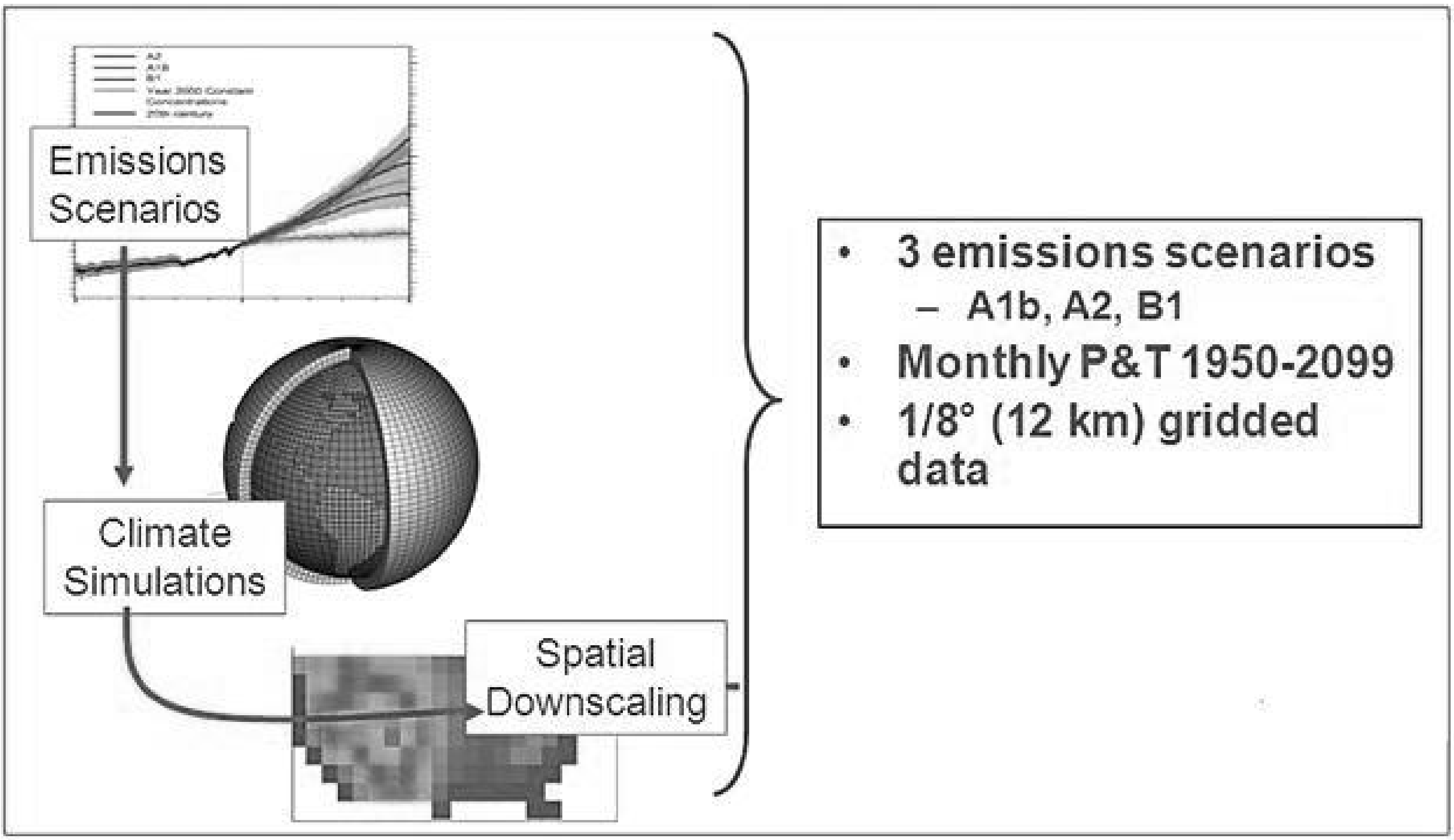

RECLAMATION

*Managing Water in the West*

**To:** Debra Willard[[redacted]; Goklany, Indur[indur_goklany@ios.doi.gov]
**Cc:** Virginia Burkett[virginia_burkett@usgs.gov]
**From:** Nowakowski, Judy
**Sent:** 2017-05-19T13:21:12-04:00
**Importance:** Normal
**Subject:** Fwd: climate history briefing
**Received:** 2017-05-19T13:23:22-04:00
INFORMATION_Goks_USGS_edits_5-19-17.docx

Thanks so much, Deb! I'm forwarding it straight to Goks and suggesting the two of you work together directly on it from here on (it's way past me now!) and just keep me in the loop.

---------- Forwarded message ----------
From: **Willard, Debra** <dwillard@usgs.gov>
Date: Fri, May 19, 2017 at 1:08 PM
Subject: climate history briefing
To: Judy Nowakowski <jnowakowski@usgs.gov>

Hi Judy,
Here's the updated climate history piece. [redacted]

I added several figures that could be modified as needed. I haven't added in the citations yet, because I wanted to see if there are further modifications.

Thanks for the help with this.

Best,
Deb

--------------------------------------------------------------------------------
Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

## INFORMATION/BRIEFING MEMORANDUM

DATE: May 11, 2017
FROM: Bill Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations of past change help provide critical context for policy makers and resource managers in the Department of the Interior and other agencies to be responsible stewards for Federal lands and our Nation's treasures. These studies also provide a scientific basis to anticipate and plan for important societal and ecological impacts of future changes in climate and land use.

**Commented [GIM1]:** I would move to end of para

### KEY TAKEAWAYS

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in: the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the atmosphere.
- Over millions to hundreds-of-thousands of years, changes in climate have been governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), changes in the extent of continent-scale glaciers and sea ice, and variations in atmospheric chemistry.
- During the past ~2,600,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). Detailed records of the last 800,000 years were captured by the EPICA Dome C ice core from

**Commented [GIM2]:** Consider, e.g., Himalayas and the Tibetan Plateau

**Commented [Office3]:** I'd leave this as it is

**Commented [GIM4]:** Divided the above bullet in two

**Commented [ets5]:** Longer! 2.7 My?

**Commented [DW6R5]:** I changed it to ~2.6M and added another sentence referring to the last 800,000 years.

Antarctica and illustrate the variability in various climate and environmental parameters (Figure 1). The current interglacial began about 12,000 years ago. The previous interglacial ended approximately 114,000 years ago.

- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system caused variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes occurred, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.
- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century was benign relative to the variability seen over the previous thousand years. In particular, within the lands of the United States, there were multi-decadal droughts, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest)
- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were much smaller than today. During the last few thousand years, variations in relative global sea level occurred due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers (Figure 2).
- For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period. They fluctuated between the lows during the Ice Ages of 190-200

**Commented [DW7]:** I deleted the comment below because there is a great deal of variability spatially (warmer summers in high latitudes, changes in seasonality, etc). There isn't an accurate blanket answer for the globe, but we could develop it further in the following text, if desired.

**Deleted:** (which was warmer than the current one by as much as X degrees C)

**Commented [GIM8]:** Over geologic time scales, temperatures have ranged from X degrees cooler to Y degrees warmer, and CO2 from W ppm to Z ppm. Is it possible to get a figure that summarizes temperature and CO2 levels over geologic time scales?

**Commented [DW9R8]:** See Figure 1 above

**Commented [GIM10]:** It might be useful to include a figure showing sea levels since at least the last glacial max.

**Commented [DW11R10]:** Figure 2 was added to address this.

**Commented [GIM12]:** Is this correct?

**Commented [ets13]:** Approximately – the proxies for CO2 in the earlier record are much less precise than the ice core record.

parts per million volume (ppmv) to 280 ppmv during warm interglacial periods. .

**Temperature Extremes**

The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years.

The Long-Term Geologic Record of Temperature

Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics. In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities. For example, during the mid-Pliocene Warm Period, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to longer glacial-interglacial time scales, air and ocean temperatures still

**Commented [ets14]:** No. See Parrenin, Frédéric, et al. "Synchronous change of atmospheric CO2 and Antarctic temperature during the last deglacial warming." *Science* 339.6123 (2013): 1060-1063.
In any case, the lead/lag argument is a red herring – mechanisms of CO2 and climate change involve mutual feedbacks.

**Commented [GIM15]:** Could we add a bullet on abrupt climate changes, and how rates of change compare with what we see today, keeping in mind any changes in temporal resolution?

**Commented [ets16]:** I agree: past abrupt changes have been associated with volcanic eruptions, meteorite impacts, and carbon-cycle disturbances.

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**Deleted:** time

varied considerably. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By conducting research at sites throughout North America, USGS scientists aim to determine when these changes began and ended, how widespread they were, and how they influenced ecosystems and natural resources.

**Commented [GIM17]:** Can we say something about the tree line and where it stood relative to today (to the extent known)? See, e.g., MacDonald, G. M., K. V. Kremenetski, and D. W. Beilman, "Climate change and the northern Russian treeline zone," Philosophical Transactions of the Royal Society B: Biological Sciences 363.1501 (2008): 2283-2299.

**Commented [DW18R17]:** There is substantial spatial variability in the timing and impact of the MCA; if we are to bring in those types of details, I'd rather expand one of the subsequent sections so that we could explain it more clearly. On a side note, the hydrologic changes associated with the MCA are striking.

Instrumental Records of Temperature

Instrumental measurements of land and sea surface temperatures have been collected since 1854 (toward the end of the Last Ice Age), and the National Oceanographic and Atmospheric Administration (NOAA) has calculated global averages dating from 1880. Typically, temperature anomalies are calculated relative to a 1981-2010 base period or, in the case of global averages, to the 20th century average. Many other surface temperature datasets and analyses are available at NOAA's National Climate Data Center. Historical temperature patterns also are presented by NASA's Goddard Institute for Space Studies (GISS) in a dataset called Surface Temperature Analysis (GISTEMP). This record indicates that warming temperatures have occurred since the first comprehensive records became available in the year 1880, with a higher rate of warming since approximately 1950. Since 1950, land surface air temperature has risen faster than sea surface water temperature. These records indicate that the Earth's average surface temperature has risen about 1.1 degree Celsius (2˚ F) since the late 19th century, which appears to be a larger temperature increase than that of medieval times.

**Commented [GIM19]:** 1.Do you mean that current temperatures are higher than they were during the MWP, or that "temperature increase" is higher?
2.Isn't there dispute about this? Also, what about previous warming episodes going back to the Holocene Optimum?

**Commented [ets20]:** A key point here is the rate of change, not just comparing snapshots.

**Commented [DW21R20]:** Agreed. There is a good deal of ongoing research aimed at developing high-resolution Holocene records that would be able to address the question of how rapidly past changes occurred. And, from the perspective of a terrestrial paleoecologist, the terrestrial sedimentary proxies (typically assemblage data) provide better estimates of past hydrology than temperature. Marine and estuarine proxies have been well-calibrated with temperature and salinity, but the non-tree-ring records from terrestrial deposits provide a more qualitative estimates.

## Hydrologic Extremes

The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Records of past droughts and unusually wet periods are preserved by tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together,

these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America. As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20th century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand years. Moreover, these studies will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**

Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth

**Commented [GIM22]:** Might want to put a figure here from Woodhouse/Cook work illustrating drought and wet periods in the southwest USA.

**Commented [DW23R22]:** Done - see figure 3 below

**Commented [GIM24]:** When?

**Formatted:** Superscript

of ice sheets were the primary influence on sea level. Sea level is low during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels during the last glaciation were 125 meters (410 feet) lower than today.

During the last interglacial period (~125,000 years ago), sea levels were about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example, melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that one sees depends on where and when one looks. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to local subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting causal mechanisms is a priority research area.

**Commented [GIM25]:** Might want to consider introducing a figure to show global extent of Ice Sheet and Ocean margins ~20,000 years ago.

**Commented [DW26R25]:** Done – see Figure 2

**Commented [GIM27]:** I recommend putting a figure here showing sea level changes since at least the last glacial max. I would also say something about how rapidly sea levels have fluctuated in the past to provide context for changes currently being experienced.

**Commented [DW28R27]:** See Figure 2 for sea level and ice sheet changes.

I'm not sure how to clearly knit this into the existing discussion because I'm mixing time periods. So, here's the information, and please advise how/if to incorporate into the existing text (if we were to expand this to a larger piece, it would be pretty easy):

During the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters per century (Deschamps et al., 2012, Nature 483: 559-564).

**Commented [ets29]:** I agree – the comparison of rates is very important.

**Carbon Cycle Variability**

Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

**Commented [GIM30]:** Can we say something about biological productivity through geologic time as correlated with CO2 levels?

**Commented [ets31]:** We wish!

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where the records extend back 800,000 years, covering the last eight ice ages. Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

**Commented [GIM32]:** Why can't we go back further?

**Commented [ets33]:** The deepest core is EPICA/Dome C, drilled to ~3200m where total ice depth is ~3300m, and the maximum age is 800 kyr.

**Commented [GIM34]:** Hasn't the rise in CO2 followed warming in these ice cores?

**Commented [ets35]:** See response above.

**Commented [GIM36]:** Curious – Does coastal perimeter make a difference?

**Commented [DW37R36]:** I'm not sure what you're getting at. If sea level rises substantially and covers the wetlands, I suppose that could affect methane exchange. Would need a better understanding of the question before I try to answer it.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle

include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released soil carbon into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), but the most significant impacts are observed after European colonists began clearing forests as early as 1700 AD.

**Commented [GIM38]:** Is there any indication of change in accumulation rates since global biological productivity seems to have been enhanced according to recent satellite data possibly due to CO2 emissions, agricultural practices and climate change. See also here. By the way, assuming the latter paper is "correct", doesn't it indicate higher productivity today vs. 1750, despite all the deforestation? Is that correct?

**Commented [ets39]:** These are records of gross primary productivity (GPP), which represents plant productivity during the growing season and does not include respiration by plants and soils. The effect is not clear for net primary productivity, which takes respiration into account.

**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are seeing the results of a broad range of changes(?) that span the history of the Earth. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

**FIGURES**

**Figure 1** – $CO_2$ records and EPICA Dome C temperature anomalies over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

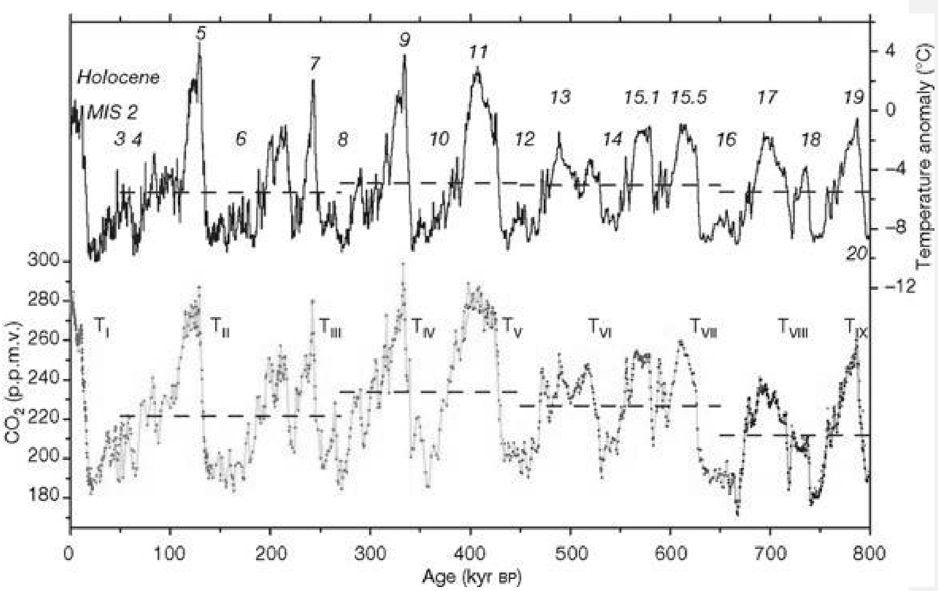


Figure 2 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum at 21,000 years ago to the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much broader (from Bartlein et al., 2014).

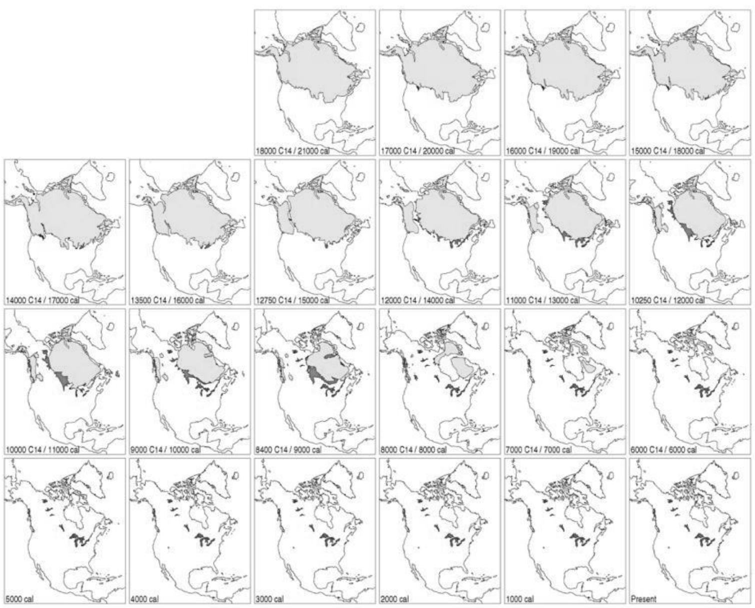
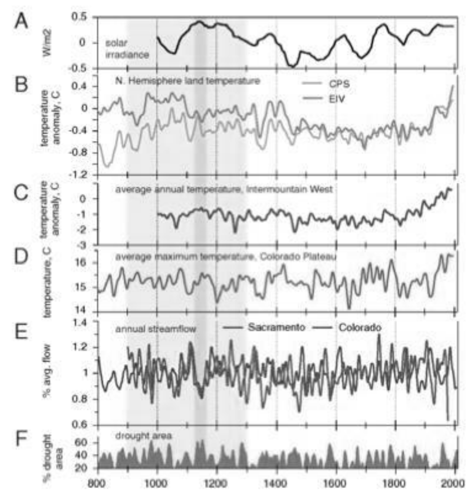


Figure 3 – Global, hemispheric, and regional proxy and model data documenting medieval period conditions. A Solar irradiance (69), B two estimates of Northern Hemisphere land temperatures, departures from 1850–1995 (32), C ECHO-G (60) modeled average annual temperature for 34°–40° N, 104°–124° W, and departures from 1890–1990, D reconstructed Colorado Plateau mean maximum temperatures (13), E reconstructed water year streamflow, Colorado River at Lees Ferry (41) and Sacramento Four Rivers index flow (40), percent of average based on AD 901–1977, and F reconstructed Southwest Drought Area Index (5). All series except (A) were smoothed with a 20-year spline. Light Shading indicates medieval period, Dark Shading indicates mid-1100s period. (from Woodhouse et al., 2010).

**Commented [DW40]:** I pulled the figure and caption directly from the Woodhouse et al. (2010) paper for now. I could create a new plot that shows streamflow only or some other combination of reconstructions – please let me know what you'd prefer.

**Global, hemispheric, and regional proxy and model data documenting medieval period conditions.**




**Connie A. Woodhouse et al. PNAS 2010;107:21283-21288**



PNAS

17-01174_012520;17-01174_012520

**To:** Debra Willard[[redacted]]; Virginia Burkett[virginia_burkett@usgs.gov]
**Cc:** Nowakowski, Judy[jnowakowski@usgs.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-23T09:57:58-04:00
**Importance:** Normal
**Subject:** Re: climate history briefing
**Received:** 2017-05-23T09:58:32-04:00
INFORMATION_Goks_USGS_edits_5-23-17.docx

Attached are my comments and edits. Most of these relate to the figures. [redacted]

Thanks.

On Fri, May 19, 2017 at 1:21 PM, Nowakowski, Judy <jnowakowski@usgs.gov> wrote:

> Thanks so much, Deb! I'm forwarding it straight to Goks and suggesting the two of you work together directly on it from here on (it's way past me now!) and just keep me in the loop.

---------- Forwarded message ----------
From: **Willard, Debra** <dwillard@usgs.gov>
Date: Fri, May 19, 2017 at 1:08 PM
Subject: climate history briefing
To: Judy Nowakowski <jnowakowski@usgs.gov>

Hi Judy,
Here's the updated climate history piece. There is one request that I just realized I didn't reply to [redacted] but I wanted to get this back to you now.

I added several figures that could be modified as needed. I haven't added in the citations yet, because I wanted to see if there are further modifications.

Thanks for the help with this.

Best,
Deb


--------------------------------------------------------------------------------
Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

**INFORMATION/BRIEFING MEMORANDUM**

DATE: May 11, 2017
FROM: Bill Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations of past change help provide critical context for policy makers and resource managers in the Department of the Interior and other agencies to be responsible stewards for Federal lands and our Nation's treasures. These studies also provide a scientific basis to help anticipate and plan for important societal and ecological impacts of future changes in climate and land use.

**KEY TAKEAWAYS**

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in: the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the atmosphere. See Figure 1.
- Over millions to hundreds-of-thousands of years, changes in climate have been governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), changes in the extent of continent-scale glaciers and sea ice, and variations in atmospheric chemistry.
- During the past ~2,600,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). Detailed records of the last 800,000 years were captured by the EPICA Dome C ice core from

**Commented [GIM1]:** Consider, e.g., Himalayas and the Tibetan Plateau

**Commented [Office2]:** I'd leave this as it is

**Commented [GIM3R2]:** In or out? I'll leave it to your judgment.

**Commented [GIM4]:** It's appended at the back of this document. From: Royer DL. Atmospheric CO2 and O2 during the Phanerozoic: Tools, patterns, and impacts. Treatise on Geochemistry. 2014;6:251-67. Appended at the back. It has two panels: Temperature at the top and CO2 at the bottom from ~65 Mya to the present. I wish it had error bars for the former. I'll keep looking. If a good substitute cannot be found, perhaps the caption should include something to the effect that temps are not precise should be viewed as qualitative rather than quantitative (but then most of the other figures also lack error bars!).

Antarctica and illustrate the variability in various climate and environmental parameters (Figure 2). During the Last Glacial Maximum (~ 21,000 years ago), ice sheets, more than a mile high in many places, covered substantial portions of the Northern and Southern Hemispheres. In North America they extended as far south as Illinois (Figure 3). The current interglacial began about 12,000 years ago. The previous interglacial ended approximately 114,000 years ago.

- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system caused variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes occurred, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.
- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century was benign relative to the variability seen over the previous thousand years. In particular, within the lands of the United States, there were multi-decadal droughts, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest) (Figure 4).
- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were much smaller than today. During the last few thousand years, variations in relative global sea level occurred

**Commented [GIM5]:** It's attached at the back. From Cook et al. (2014).

due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers (Figure 5).

- For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period (Figure 1). They fluctuated between the lows during the Ice Ages of 190-200 parts per million volume (ppmv) to 280 ppmv during warm interglacial periods. .

**Commented [GIM6]:** Also at the back. It's from Siddall et al (2003). It shows error bars and one can discern from it that SL has been higher in the past.

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**Commented [GIM7]:** Could we add a bullet on abrupt climate changes, and how rates of change compare with what we see today, keeping in mind any changes in temporal resolution?

**Commented [GIM8R7]:** Not sure we have a bullet on abrupt CC.

**Commented [ets9]:** I agree: past abrupt changes have been associated with volcanic eruptions, meteorite impacts, and carbon-cycle disturbances.

## Temperature Extremes

The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years (Figure 1).

The Long-Term Geologic Record of Temperature

Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics (Figure 2). In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities. For example, during the mid-Pliocene Warm Period, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to

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improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to longer glacial-interglacial time scales, air and ocean temperatures still varied considerably. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By conducting research at sites throughout North America, USGS scientists aim to determine when these changes began and ended, how widespread they were, and how they influenced ecosystems and natural resources.

Instrumental Records of Temperature

Instrumental measurements of land and sea surface temperatures have been collected since 1854 (toward the end of the Last Ice Age), and the National Oceanographic and Atmospheric Administration (NOAA) has calculated global averages dating from 1880. Typically, temperature anomalies are calculated relative to a 1981-2010 base period or, in the case of global averages, to the 20th century average. Many other surface temperature datasets and analyses are available at NOAA's National Climate Data Center. Historical temperature patterns also are presented by NASA's Goddard Institute for Space Studies (GISS) in a dataset called Surface Temperature Analysis (GISTEMP). This record indicates that warming temperatures have occurred since the first comprehensive records became available in the year 1880, with a higher rate of warming since approximately 1950. According to the IPCC, this rate may have slowed down since the 1990s but this has been disputed. Since 1950, land surface air temperature has risen faster than sea surface water temperature. These records indicate that the Earth's average surface

**Commented [GIM10]:** See:
- IPCC AR5 WG1, Ch9,
  - Page 768, Fig 9.8(a) and Box 9.2: "The observed global mean surface temperature (GMST) has shown a much smaller increasing linear trend over the past 15 years than over the past 30 to 60 years (Section 2.4.3, Figure 2.20, Table 2.7; Figure 9.8; Box 9.2 Figure 1a, c). Depending on the observational data set, the GMST trend over 1998–2012 is estimated to be around one-third to one-half of the trend over 1951–2012 (Section 2.4.3, Table 2.7; Box 9.2 Figure 1a, c)." [p. 769.]
- However, Karl et al. (2015), available here, claim the discrepancy was due an artifact of the data. They argue that the input data (used for observations, especially for oceans) are biased by past practices. Once Karl et al. corrected for these biases, the discrepancy between the two rates of warming more or less disappears..
- Yet others argue that the slowdown is real. See Fyfe et al (2016), available here. See Figure 2.

temperature has risen about 1.1 degree Celsius (2˚ F) since the late 19th century, which appears to be a larger temperature increase than that of medieval times.

**Commented [GIM11]:** 1.Do you mean that current temperatures are higher than they were during the MWP, or that "temperature increase" is higher?
2.Isn't there dispute about this? Also, what about previous warming episodes going back to the Holocene Optimum?

**Commented [GIM12]:** I would delete this. (A) If you are talking about absolute temperatures. I believe that it's unclear whether the MCA/MWP, call it what you will, was warmer than it is today. (B) If on the other hand you are referring to a "temperature increase", the situation is confounded by the temp dip during the LIA.

**Commented [ets13]:** A key point here is the rate of change, not just comparing snapshots.

## Hydrologic Extremes

The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Records of past droughts and unusually wet periods are preserved by tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America (Figure 4). As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20th century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

**Commented [GIM14]:** Might want to put a figure here from Woodhouse/Cook work illustrating drought and wet periods in the southwest USA.

**Commented [DW15R14]:** Done - see figure 3 below

**Commented [GIM16R14]:** I would use the Cook et al (2014) figure provided at the back.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand

years. Moreover, these studies will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**

Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth of ice sheets were the primary influence on sea level. Sea level is low during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels during the last glaciation were 125 meters (410 feet) lower than today.

During the last interglacial period (~125,000 years ago), sea levels were about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

Since the last glaciation, there have been instances of rapid sea level rise due to sudden releases of meltwater from ice sheets or the bursting of ice dams (Figure 5). For example, during the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters (13 feet) per century.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example,

**Commented [GIM17]:** I recommend putting a figure here showing sea level changes since at least the last glacial max. I would also say something about how rapidly sea levels have fluctuated in the past to provide context for changes currently being experienced.

**Commented [DW18R17]:** See Figure 2 for sea level and ice sheet changes.

I'm not sure how to clearly knit this into the existing discussion because I'm mixing time periods. So, here's the information, and please advise how/if to incorporate into the existing text (if we were to expand this to a larger piece, it would be pretty easy):

During the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters per century (Deschamps et al., 2012, Nature 483: 559-564).

**Commented [GIM19R17]:** I have inserted the last para into the text. That, along with the inserted figure, takes care of this set of comments.

**Commented [ets20]:** I agree – the comparison of rates is very important.

melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that one sees depends on where and when one looks. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to local subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting causal mechanisms is a priority research area.

**Carbon Cycle Variability**

Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from

ice cores. The longest ice cores come from Antarctica, where the records extend back 800,000 years, covering the last eight ice ages. Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released soil carbon into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), but the most significant impacts are observed after European colonists began clearing forests as early as 1700 AD.

**Implications of past variability for management of natural resources**

**Commented [GIM21]:** Why can't we go back further?

**Commented [ets22]:** The deepest core is EPICA/Dome C, drilled to ~3200m where total ice depth is ~3300m, and the maximum age is 800 kyr.

**Commented [GIM23R22]:** Although it's not important for this exercise, I was wondering why we don't have an ice core that goes further back, considering the Antarctic Ice Sheet is older than 8oo kya. Does the pressure/weight from the ice "column" melt the ice?

**Commented [GIM24]:** Curious – Does coastal perimeter make a difference?

**Commented [DW25R24]:** I'm not sure what you're getting at. If sea level rises substantially and covers the wetlands, I suppose that could affect methane exchange. Would need a better understanding of the question before I try to answer it.

**Commented [GIM26R24]:** Again, it's not important for this exercise but my thought was that eyeballing a map of the world it seems that the perimeter of the ocean margin in the NH should be longer than of the SH. Would this not suggest that there might be more submerged lands in the NH, and, hence, more methane generation there (all else being equal)?

**Commented [GIM27]:** Is there any indication of change in accumulation rates since global biological productivity seems to have been enhanced according to recent satellite data possibly due to CO2 emissions, agricultural practices and climate change. See also here. By the way, assuming the latter paper is "correct", doesn't it indicate higher productivity today vs. 1750, despite all the deforestation? Is that correct?

**Commented [ets28]:** These are records of gross primary productivity (GPP), which represents plant productivity during the growing season and does not include respiration by plants and soils. The effect is not clear for net primary productivity, which takes respiration into account.

**Commented [GIM29R28]:** According to IPPC AR5, WG2, Chapter 4, page 293:

*During the decade 2000–2009, **land net primary productivity** at the global scale continued to be enhanced about 5% relative to the estimated preindustrial level, leading to a land sink of 2.6 + 1.2 PgC yr$^{-1}$ (these values are from WGI AR5 Section 6.3.2.6; the uncertainty range is 2 standard deviations; for the primary literature see also Raupach et al., 2008; Le Quéré et al., 2009).*

I have provided the emphasis (in bold). However, I have not checked the references provided.

By integrating geological and instrumental records of past climate, scientists are seeing the results of a broad range of changes(?) that span the history of the Earth. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

# FIGURES

Figure 1 –

Source: Royer DL. Atmospheric CO2 and O2 during the Phanerozoic: Tools, patterns, and impacts. Treatise on Geochemistry. 2014;6:251-67.

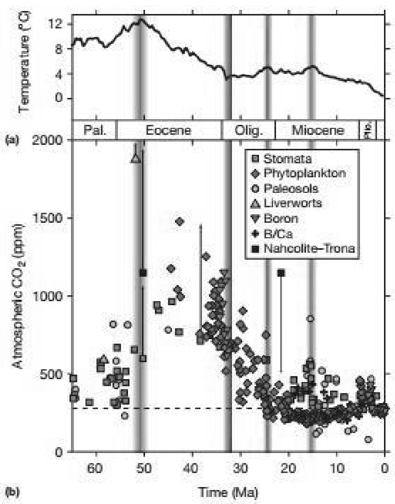


**Figure 6** $CO_2$–temperature coupling during the Cenozoic. (a) Global-mean surface temperature, as calculated from the benthic $\delta^{18}O$ compilation of Zachos et al. (2008) and following the protocol of Hansen et al. (2008). Temperature is expressed relative to the preindustrial. (b) Individual $CO_2$ estimates, coded by proxy type. See Table 1 for data sources. Estimates with arrows are unbounded. Red bands correspond to pulses in global warmth; the blue band corresponds to the rapid cooling coincident with the inception of Antarctic ice growth (Zachos et al., 2008). Dashed line represents preindustrial $CO_2$ concentration (280 ppm). This figure is updated from Beerling and Royer (2011).

**Figure 2** – $CO_2$ records and EPICA Dome C temperature anomalies over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

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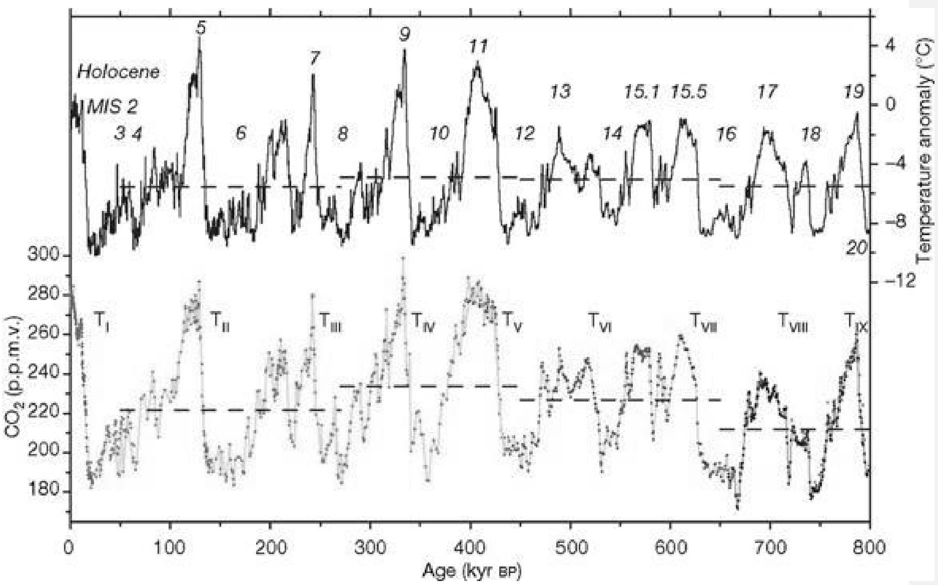
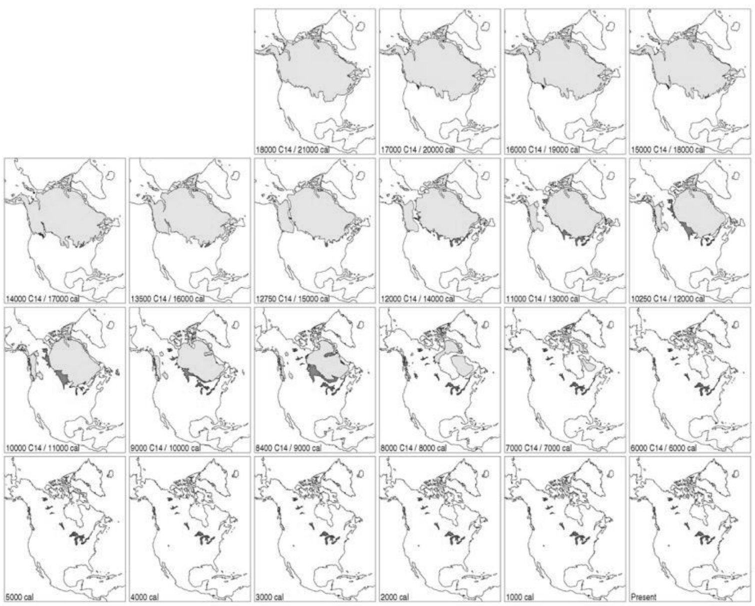


Figure 3 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum at 21,000 years ago to the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much broader (from Bartlein et al., 2014).




**Commented [GIM30]:** 1.All these panels make for a very busy figure. If it's possible, I recommend using no more than 3 panels (e.g., from 21 kya, 10 kya, and present). You have to strain to see changes in ocean margins.
2. For sea level rise I would suggest using the figure from Siddall et al (2003) or Grant et al (2014). I prefer the former because it shows error bars and also it is easier to discern from it that SL has apparently also been higher in the past (since LGM). The latter affirms that SLs have fluctuated with glaciations and deglaciations, but one could have inferred that from the previous figure in any case.

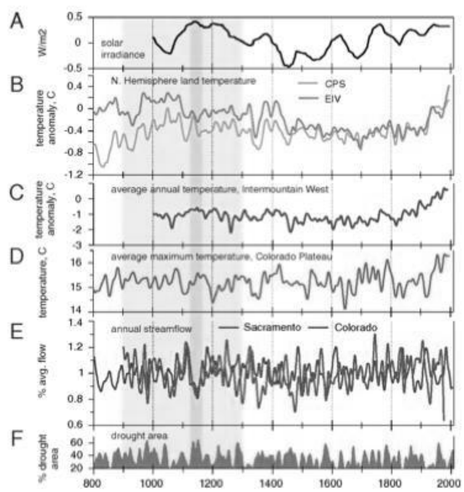
**Deleted:** __).

Figure 4 – Global, hemispheric, and regional proxy and model data documenting medieval period conditions. A Solar irradiance (69), B two estimates of Northern Hemisphere land temperatures, departures from 1850–1995 (32), C ECHO-G (60) modeled average annual temperature for 34°–40° N, 104°–124° W, and departures from 1890–1990, D reconstructed Colorado Plateau mean maximum temperatures (13), E reconstructed water year streamflow, Colorado River at Lees Ferry (41) and Sacramento Four Rivers index flow (40), percent of average based on AD 901–1977, and F reconstructed Southwest Drought Area Index (5). All series except (A) were smoothed with a 20-year spline. Light Shading indicates medieval period, Dark Shading indicates mid-1100s period. (from Woodhouse et al., 2010).

**Commented [DW31]:** I pulled the figure and caption directly from the Woodhouse et al. (2010) paper for now. I could create a new plot that shows streamflow only or some other combination of reconstructions – please let me know what you'd prefer.

**Commented [GIM32R31]:** Looks very busy because of the multiple variables it seeks to illustrate. Also I think substantial GCM modeling output seems to have been used. I would recommend using Figure 3 from Cook et al. (2014) or something similar. It's on the next page. [BTW, what are CPS and EIV in panel B?]

**Global, hemispheric, and regional proxy and model data documenting medieval period conditions.**




**Connie A. Woodhouse et al. PNAS 2010;107:21283-21288**



PNAS

Source: Figure 3 from Cook et al. (2014) illustrating frequency and duration of drought index in various parts of the US. This uses tree ring only data (I believe) and goes from 1000-2005 AD. I would modify caption to spell out the abbreviations.

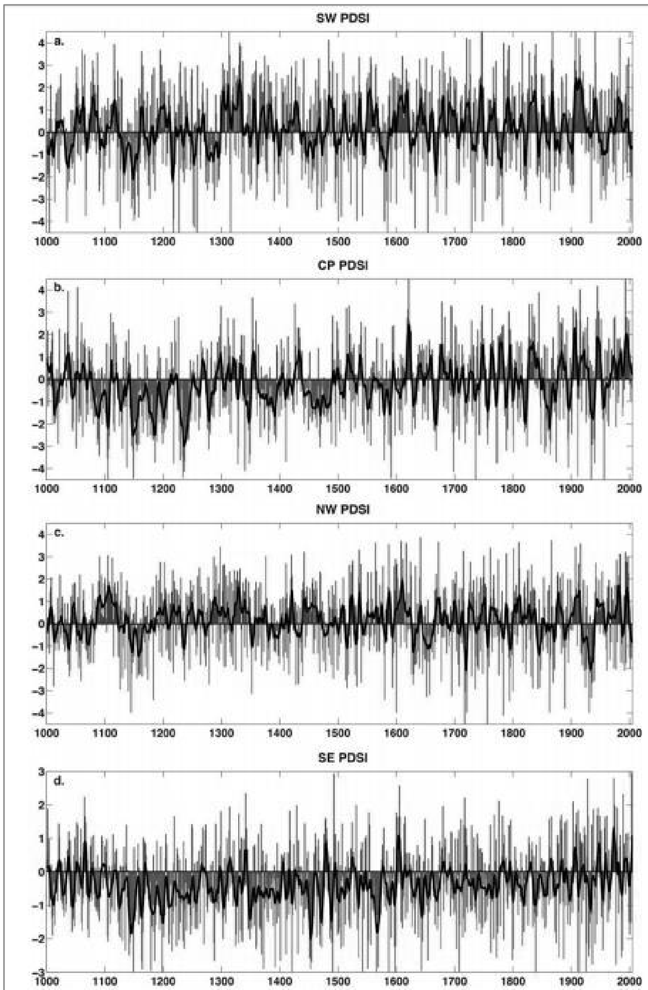
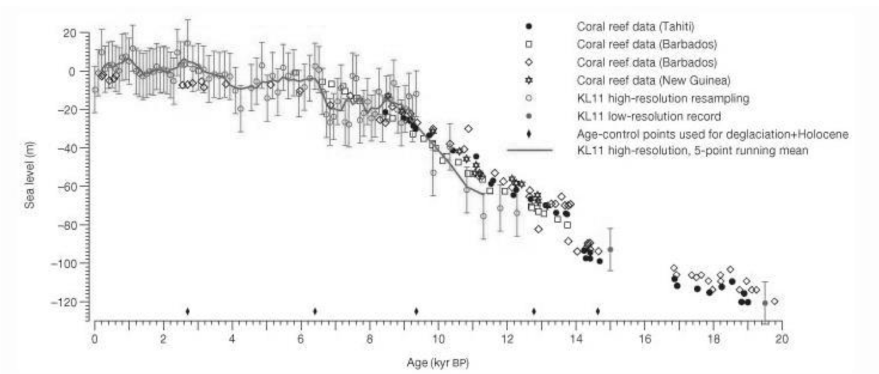



FIG. 3. Area-averaged PDSI from the NADA for the (a) SW, (b) CP, (c) NW, and (d) SE regions, as shown in Figs. 1 and 2. Green and brown bars are the original data, and dark black lines are a smoothed version of the time series using a 10-yr LOWESS spline.

Fig. 5
From Siddall et al. (2003) available at:
http://www.nature.com/nature/journal/v423/n6942/full/nature01690.html




Caption: Chronology is based on calibrated radiocarbon datings. The record is zeroed to modern sea level.

17-01174_012536;17-01174_012536;17-01174_012537;17-01174_012538

**To:** Erath, Amanda[aerath@usbr.gov]
**Cc:** David Raff[draff@usbr.gov]; Marketa Elsner[mmcguire@usbr.gov]; Avra Morgan[aomorgan@usbr.gov]; Dahm, Katharine[kdahm@usbr.gov]; Arlan Nickel[anickel@usbr.gov]
**From:** Goklany, Indur
**Sent:** 2017-05-25T11:20:10-04:00
**Importance:** Normal
**Subject:** Re: Climate discussion
**Received:** 2017-05-25T11:21:56-04:00
Uncertainty discussion for Summary.docx
KRBS_Full_Report_Final.ig.docx

Amanda,
Attached are my comments/edits to Chapter 3.9 of the main report and suggestions for the uncertainty discussion in the Summary Report.

I also received a copy of the Niobrara Report (only the Summary and appendices). But my suggestion is let's do one at a time. Once we have wrestled with the Klamath report, it should be easier to address that.

Thanks, and best regards.

Goks

On Thu, May 18, 2017 at 5:05 PM, Erath, Amanda <aerath@usbr.gov> wrote:

> Hello Goks,
> Below is the uncertainty language that we have drafted to be added to the Klamath River Basin Study Summary Report. I have also attached the Klamath River Basin Study Full Report. Sorry for the oversight in not sending the Full Report to you. The Full Report includes uncertainty discussions near the end of chapters 3, 4, 5, and 6 (identified in the table of contents for each chapter) [redacted] (b)(5) lease let me know if you have any questions.

[redacted] (b)(5)

***Amanda Erath***
*Program Analyst*
Policy and Administration
Denver Federal Center
Building 67 (84-51000)
P.O. Box 25007
Denver, CO 80225-0007

*Office*: (303) 445-2766
*Email*: aerath@usbr.gov

On Fri, May 12, 2017 at 8:55 AM, David Raff <draff@usbr.gov> wrote:

Thanks. We'll read as well and incorporate into our uncertainty language as appropriate.

---

On: 12 May 2017 08:38, "Goklany, Indur" <indur_goklany@ios.doi.gov> wrote:

[redacted] (b)(5)

On Thu, May 11, 2017 at 3:59 PM, Raff, David <draff@usbr.gov> wrote:

Good Afternoon Again Goks,

[redacted] (b)(5)

Regardless be looking for a uncertainty discussion from us for the summary report in a few days / week timeframe.

Thanks,
Dave

--
David Raff, PhD, PE | Science Advisor and Scientific Integrity Officer | Department of the Interior Bureau of Reclamation | 1849 C Street NW, Washington DC 20240 | draff@usbr.gov | 303-445-4196 (O) | 202-440-1284 (C)

17-01174_012536;17-01174_012536;17-01174_012537;17-01174_012538

RECLAMATION

*Managing Water in the West*

**Final Report**

# Klamath River Basin Study

**Technical Memorandum 86-68210-2016-06**

**Prepared by:**
**Klamath River Basin Study Technical Working Group**

U.S. Department of the Interior
Bureau of Reclamation

State of California
Department of Water Resources

State of Oregon
Water Resources Department

March 2016

## Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Abbreviations and Acronyms

| | |
|---|---|
| AF | acre-feet |
| AFY | acre-feet per year |
| BA | Biological Assessment |
| Basin Study | Klamath River Basin Study |
| BCSD | bias corrected and statistically downscaled |
| BiOp | Biological Opinion |
| BLM | Bureau of Land Management |
| CDFG | California Department of Fish and Game (became CDFW in 2013) |
| CDFW | California Department of Fish and Wildlife |
| CDWR | California Department of Water Resources |
| CEQA | California Environmental Quality Act |
| cfs | cubic feet per second |
| CMIP3 | Coupled Model Intercomparison Project, Phase 3 |
| CMIP5 | Coupled Model Intercomparison Project, Phase 5 |
| COPCO | California Oregon Power Company |
| CRLE | complementary relationship lake evaporation |
| CRS | Congressional Research Service |
| CT | central tendency |
| CVP | Central Valley Project |
| degrees C | degrees Celsius |
| degrees F | degrees Fahrenheit |
| DPS | distinct population segment |
| DRI | Desert Research Institute |
| EIS/EIR | environmental impact statement/environmental impact report |
| ENSO | El Niño/southern oscillation |
| EOM | end of month |
| EPA | U.S. Environmental Protection Agency |
| ESA | Endangered Species Act |
| ET | evapotranspiration |
| $ET_c$ | crop evapotranspiration |
| $ET_o$ | reference evapotranspiration |
| FAO | Food and Agriculture Organization of the United Nations |

| | |
|---|---|
| FERC | Federal Energy Regulatory Commission |
| GCM | general circulation model |
| GDD | growing degree days |
| gpcd | gallons per capita per day |
| HD | hot-dry |
| HDe | ensemble hybrid delta method |
| HUC | hydrologic unit code |
| HW | hot-wet |
| Interior | U.S. Department of the Interior |
| IPCC | Intergovernmental Panel on Climate Change |
| KAF | thousands of acre-feet |
| KBPM | Klamath Basin Planning Model |
| KBRA | Klamath Basin Restoration Agreement |
| KHSA | Klamath Hydropower Settlement Agreement |
| LKNWR | Lower Klamath National Wildlife Refuge |
| M&I | municipal and industrial |
| MODFLOW | modular finite-difference flow (model) |
| MWAT | maximum weekly average temperature |
| NEPA | National Environmental Policy Act |
| NIWR | net irrigation water requirement |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| NWR | National Wildlife Refuge |
| OWRD | Oregon Water Resources Department |
| PDO | Pacific decadal oscillation |
| PDSI | Palmer drought severity index |
| $P_e$ | effective precipitation |
| PET | potential evapotranspiration |
| P.L. | Public Law |
| PM | Penman Monteith dual crop coefficient method |
| Prcp | mean annual precipitation |
| Project | Reclamation's Klamath Project |
| PRMS | precipitation runoff modeling system |
| Reclamation | Bureau of Reclamation |
| RBM10 | River Basin model-10 |
| RO | runoff |

| | |
|---|---|
| SECURE | Science and Engineering to Comprehensively Understand and Responsibly Enhance |
| SONCC ESU | Southern Oregon/Northern California Coast Ecologically Significant Unit |
| SWE | snow water equivalent |
| Tavg | mean daily average temperature |
| $T_{max}$ | maximum daily air temperature |
| $T_{min}$ | minimum daily air temperature |
| TMDL | total maximum daily load |
| TWG | technical working group |
| UKL | Upper Klamath Lake |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| VIC | variable infiltration capacity (model) |
| WaterSMART | Sustain and Manage America's Resources for Tomorrow |
| WD | warm-dry |
| WW | warm-wet |
| WWCRA | West-Wide Climate Risk Assessments |

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# Chapter 1
# Klamath River Basin Study Introduction

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# Contents

# Figures



# Tables

# Chapter 1
# Introduction

## 1.1 Background

The Klamath River Basin is the second largest watershed in the State of California (approximately 15,700 square miles), after the Sacramento River Basin (approximately 27,900 square miles; see Figure 1-1). Approximately 60 percent of the watershed is public land (U.S. Geological Survey [USGS], 2007). It supports habitats and numerous fish and wildlife species in addition to supplying water for agriculture, hydropower, recreation, the environment, and tribal, municipal, industrial, and domestic uses. The watershed is divided by the Cascade and Siskiyou Mountains, which create two distinct climates: an arid climate in the upper basin, generally east of the mountains, and a maritime climate in the lower basin. The upper portion of the basin covers approximately 38 percent of the watershed but contributes only 12 percent of the entire watershed's annual flow (Congressional Research Service [CRS], 2005). The lower portion of the basin covers approximately 62 percent of the watershed, yet contributes 88 percent of the watershed's annual flow. The primary tributary inflows are located in the Lower Klamath Basin and include the Shasta, Scott, Salmon, and Trinity Rivers.

The Klamath River Basin has a history of complex water management challenges, dating back more than a century. In large part, these challenges relate to the competing needs of the various mainstem users, irrigation diversions on the Scott, Shasta, and Trinity Rivers (tributaries to the Klamath), and the construction of six mainstem dams (see Figure 1-1), which have altered the natural flow and nutrient and sediment regimes in the river and have inhibited upstream passage of migratory fish above Iron Gate Dam (river mile 190).

Managers of natural resources in the Klamath River Basin have long called for a comprehensive and integrated approach to water management. In 2008, the National Research Council reported that "the most important characteristics of research for complex river-basin management were missing for the Klamath River: the need for a 'big picture' perspective based on a conceptual model encompassing the entire basin and its many components" (Thorsteinson et al., 2011).

---

[1] Figure 1-1 produced by Michael Neuman, Klamath Basin Area Office of the Bureau of Reclamation

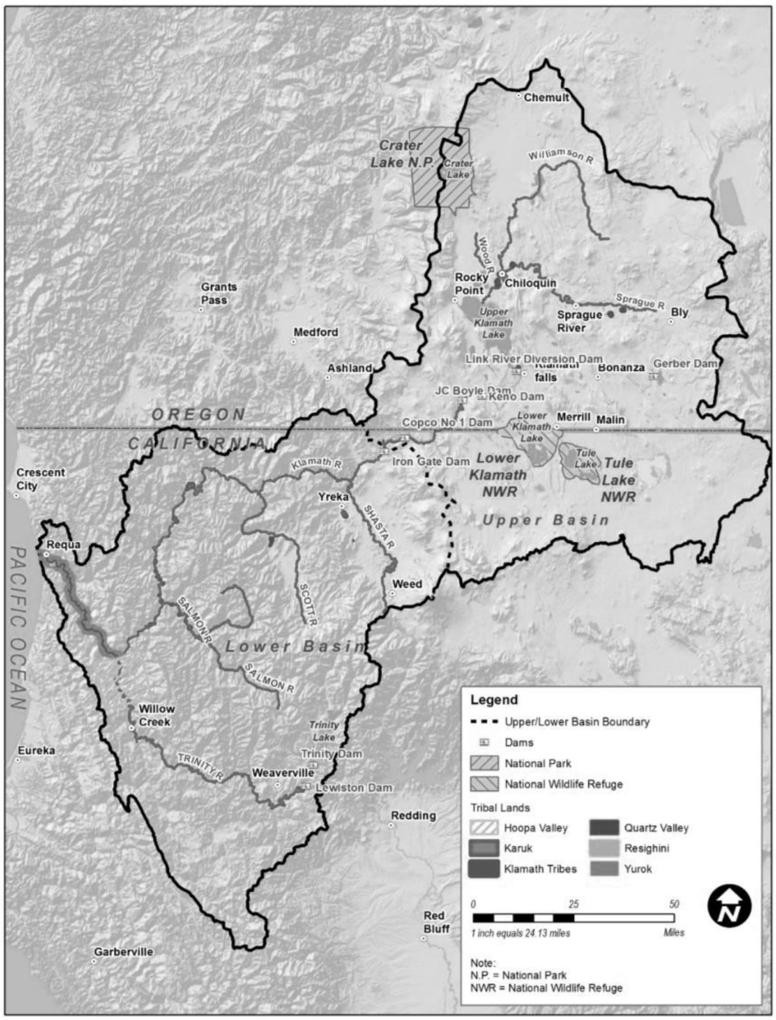


**Figure 1-1. Klamath River Basin overview map**

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to achieve future water security. The Bureau of Reclamation (Reclamation) serves as the U.S. Department of the Interior's (Interior) primary water management agency. It developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (Public Law

[P.L.] 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program, which was developed as a result. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management.

The Klamath River Basin Study commenced in September 2012. Non-federal cost share partners for the study include the California Department of Water Resources (CDWR) and the Oregon Water Resources Department (OWRD). It should be noted that the Klamath River Basin Study:

- Does not require federal or state environmental review
- Does not contain recommendations for action
- Is not a decisional document

This first chapter of the Klamath River Basin Study provides an overview of the basin, identifies the study purpose, scope, and objectives, and discusses the overall process of the basin study. This chapter also outlines the collaboration and outreach process, which is a significant component of the Klamath River Basin Study.

## 1.2 Purpose, Scope, and Objectives of the Study

The purpose of the Klamath River Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances. Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessment (WWCRA) but contain additional information, if available (refer to Reclamation [2011d] for water supply assessment; demand assessment is currently under development). The WWCRA is an ongoing complementary activity in the Basin Studies Program in which Reclamation is developing a comprehensive and consistent set of hydro-climate data resources west-wide by incorporating the best available science. These data resources provide a baseline for climate change adaptation planning.

More specifically, basin studies seek to build on existing knowledge through studies, reports, and stakeholder collaboration. The following objectives are key components of each basin study:

- Assess current and projected future water supply
- Assess current and projected future water demand
- Evaluate current and projected future system reliability with respect to chosen performance measures

- Identify and evaluate potential adaptation strategies that may reduce any imbalances

The Klamath River Basin has a long history of water management challenges. Numerous studies have been conducted that evaluate the projected impacts of climate change in the region (e.g., Reclamation, 2011; Risley et al., 2012; Oregon Climate Change Research Institute, 2010; National Center for Conservation Science and Policy, 2010) and explore potential adaptation strategies (e.g., increase offstream storage) that may mitigate the impact. The Klamath River Basin Study seeks to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a modeling and decision support framework that allows for exploration of a range of management strategies.

## 1.3 Location and Description of the Study Area

### 1.3.1 Geographic and Geologic Setting

The Klamath River flows over 253 miles from its headwaters north of (and including part of) Crater Lake National Park in Oregon to its outflow at the Pacific Ocean in Requa, California (Figure 1-1). The Klamath River Basin includes all or parts of Klamath, Lake, Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties. Five national forests intersect the Klamath River Basin: Six Rivers, Klamath, Shasta-Trinity, Modoc, and Winema. The Klamath River Basin also contains a substantial amount of land managed by the Bureau of Land Management. From a water management perspective, the basin is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam: the upper portion (hereafter referred to as "Upper Klamath Basin"), and the lower portion (hereafter referred to as "Lower Klamath Basin"). The Upper Klamath and Lower Klamath Basins generally have differing climates and management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake and the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range and Siskiyou Mountains. The primary tributaries to the Klamath River above Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin.[2] The mean annual flow of

[2] Major tributary flow as percentage of Klamath River flow (44%) was reported by BLM (1990) and verified by computing the percentage on a mean annual basis (water years 1951-2012) using the

the Klamath River is about 17,900 cubic feet per second. Eleven miles of the Klamath River between the J.C. Boyle Powerhouse and the California-Oregon border were designated as "scenic" in 1994 under the National Wild and Scenic Rivers System (P. L. 90-452, October 2, 1968). The mainstem lower Klamath River from Iron Gate Dam to the Pacific Ocean, as well as reaches of the Scott River, Salmon River, Wooley Creek (tributary of the Salmon River), and Trinity River, are classified under the National and California Wild and Scenic River Systems (California classifications according to Public Resources Code Section 5093.50 et seq.). These classifications include "wild," "scenic," and "recreational."

The Klamath River contains six mainstem dams (Table 1-1). Link River Dam, at river mile 253 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake. Keno Dam, at river mile 232 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include: California Oregon Power Company (COPCO) 1 dam at river mile 197 (California); COPCO 2 dam at river mile 198 (California), which was constructed to reregulate flows out of COPCO 1; J.C. Boyle Dam at river mile 227 (Oregon), which was constructed primarily for producing peaking power upstream of the COPCO dams; and, Iron Gate Dam at river mile 190 (California). PacifiCorp (owned by MidAmerican Energy Holdings Company) owns and operates the hydropower producing facilities on the Klamath River under Federal Energy Regulatory Commission license 2082 and provides most of the Klamath River Basin's power (CDWR, 1960).

The Upper Klamath Basin once held pluvial Lake Modoc at an elevation of about 4,200 feet above sea level with an estimated 400 miles of shoreline and 1,000 square miles of surface area. As temperatures warmed during the Late Pleistocene, only Tule Lake, Lower Klamath Lake, and Upper Klamath Lake remained. Parts of the bed of Lake Modoc became Langell Valley and Poe Valley (Beckham, 2006). Lower Klamath and Tule Lakes are discussed further in Section 1.4.2.1. Upper Klamath Basin.

The Klamath River Basin covers three geologic provinces from east to west: the Modoc-Oregon Lava Plateau, the Cascade Range, and the Klamath Mountains. The Modoc-Oregon Lava Plateau includes nearly all of the Klamath River Basin in California east of (and including) Butte Valley. Downstream from Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a steep, coarse-grained, confined channel. From Iron Gate east to the Oregon-

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following streamflow gages: 1) USGS 11530500 Klamath R. nr Klamath, CA; 2) USGS 11522500 Salmon R. at Somes Bar, CA; 3) USGS 11519500 Scott R. nr Fort Jones, CA; 4) USGS 11517500 Shasta R. nr Yreka, CA; 5) USGS 11530000 Trinity R. at Hoopa, CA. This reported value is based on a simplified water balance which may not be an accurate accounting of the contribution of the four major tributaries to flow in the Klamath River at Klamath, CA.

California state line, the river is predominantly nonalluvial and sediment-supply-limited. The Cascade Range forms a north-south belt through the basin, extending from beyond Crater Lake on the north to Mount Shasta on the south. It is bounded in part on the east by the western edge of Butte Valley and on the west by the western edge of Shasta Valley. The Klamath Mountains province includes the entire remainder of the basin lying west of the Cascade Range (CDWR, 1960).

**Table 1-1. Summary of Klamath Basin dams**

| Dam Name | Location | Klamath River Mile | Year Completed | Reservoir Capacity (acre-feet) | Purpose |
|---|---|---|---|---|---|
| **Upper Klamath Basin** | | | | | |
| Clear Lake[1] | Lost River | NA | 1910 | 527,000 | Irrigation |
| COPCO 1 | Klamath River | 197 | 1918 | 6,235 | Hydropower |
| Link River | Klamath/Link River | 253 | 1921 | 873,000 | Control UKL level |
| COPCO 2 | Klamath River | 198 | 1925 | 73 | Hydropower |
| Gerber[1] | Miller Creek | NA | 1925 | 94,300 | Irrigation |
| JC Boyle | Klamath River | 227 | 1958 | 3,377 | Peaking power |
| Iron Gate | Klamath River | 190 | 1962 | 58,000 | Hydropower |
| Keno | Klamath River | 232 | 1966 | 18,500 | Hydropower, recreation |
| **Lower Klamath Basin** | | | | | |
| Dwinnell Dam[2] | Shasta River | NA | 1928 | 50,000 | Water supply |
| Lewiston[2] | Trinity River | NA | 1967 | 14,660 | CVP water supply |
| Trinity | Trinity River | NA | 1962 | 2,400,000 | CVP water supply |

Notes: CVP = Central Valley Project. UKL = Upper Klamath Lake
[1] Clear Lake and Gerber Reservoirs are briefly discussed in Section 4.2.1, Upper Klamath Basin.
[2] Dwinnell and Lewiston Dams are briefly discussed in Section 4.2.2, Lower Klamath Basin.

### 1.3.2 Historical Climate and Hydrology

Mean annual precipitation in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains to the west (Reclamation, 2011a). About two-thirds of the precipitation falls as snow between October and March. The annual long-term average snowfall in Klamath Falls is about 41 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 521 inches of snow annually.

Historical runoff in the Klamath River Basin is highly variable from year to year. Although precipitation predominantly occurs in the winter months, water percolates and moves through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Under natural conditions the Upper Klamath Basin area lakes have a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin

suggests that, although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011c).

All precipitation and snowmelt in the Shasta River watershed (draining to the Klamath River) percolates into the volcanic soil and appears in springs or discharges directly from the ground water into the Shasta River. The only significant surface runoff from the Cascade Range along the eastern edge of Shasta Valley occurs in the Little Shasta River (CDWR, 1960). In the Scott, Salmon, Trinity, and other tributaries of the lower Klamath River, runoff is a function of precipitation and snow storage (CDWR, 1960).

Since 1900, temperatures in the Pacific Northwest have increased by 1.0 degree Celsius, which is 50 percent greater than the global average, as reported by other studies (Knowles et al., 2007; Regonda et al., 2005; Mote, 2008). Further, the Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the mid- and late-20th century. Although observed trends of temperature, precipitation, snowpack, and streamflow in the western United States might be partially explained by anthropogenic influences on climate (Barnett et al., 2008; Pierce et al., 2008; Bonfils et al., 2008; Hidalgo et al., 2009; and Das et al., 2009), these changes are difficult to distinguish from natural climate variability (Villarini et al., 2009), particularly in the case of precipitation (Hoerling et al., 2010). Similarly, future projections of climate over the next 30 to 50 years indicate that the Klamath River Basin will continue to experience warming, as well as increased winter precipitation and decreased summer precipitation. Natural modes of variability like the El Nino/Southern Oscillation and the Pacific Decadal Oscillation (PDO) will continue to influence these general trends (Thorsteinson et al., 2011).

### 1.3.3 Vegetation, Wildlife, and Fish

The Klamath Basin is home to a diverse range of plant species. Tree species include willows, pines, ash, oak, cedar, juniper, alder, and birch. Shrubs range from poison oak and sumac to dogwood, manzanita, honeysuckle, currant, mock orange, ninebark, plum, chokecherry, crabapple, snowberry, sagebrush (several varieties), and Oregon grape. Hundreds of indigenous herbaceous plants grow in this region including orchids, lilies, paintbrushes, grasses, ferns, horsetails, and lichens (Beckham 2006).

Wildlife includes numerous mammals, birds, fish, amphibians, and reptiles. Large animals include black bear, black-tailed deer, mule deer, elk, and mountain lion. Smaller mammals range from beaver, ermine, and fisher to bats, river otter, foxes, squirrels, chipmunks, rabbits, shrews, woodrats, and voles. Numerous reptiles live in the area and include the western rattlesnake, garter snake, and pond turtle. Raptors, game birds, woodpeckers, and other water and land birds are at home in this setting. The Upper Klamath Basin is a part of the Pacific Flyway where hundreds of thousands of migrating birds stop to rest. The U.S. Fish and Wildlife

Service (USFWS) listed the northern spotted owl as threatened under the Endangered Species Act (ESA) in 1990, the shortnose and Lost River suckers as endangered in 1988, and the bull trout as threatened in 1999. The National Marine Fisheries Service (NMFS) listed the Southern Oregon/Northern California Coast Ecologically Significant Unit (SONCC ESU) of coho salmon as threatened in 1997 and reconfirmed the listing in 2005, and listed critical habitat for the threatened distinct population segment of the Pacific Eulachon in 2011, which includes the Klamath River estuary. In total three plant, eight fish, seven whale, four turtle, four bird species, and one sea lion in the vicinity of the Klamath River are ESA listed; however, the suckers, coho, and bull trout are most often affected by water management practices.

The Lower Klamath and Tule Lake National Wildlife Refuges (NWR), located in the upper Klamath Basin of Oregon and California, encompass approximately 46,700 and 39,100 acres, respectively (Risley and Gannett, 2006). According to the study by Risley and Gannett (2006), mean annual (2003–2005) water use for the Lower Klamath and Tule Lake NWRs was approximately 124,000 and 95,900 acre-feet, respectively, including precipitation and water deliveries.

The Klamath River is home to numerous resident and migrating fish species. Resident fish resources include redband trout and rainbow trout in the mainstem Klamath River (Beckham, 2006). The shortnose and Lost River sucker reside in the Upper Klamath Basin. Historically, the Klamath River was the third most productive river for salmon in the continental United States. Spring Chinook, fall Chinook, and coho salmon, as well as steelhead, spawn in reaches of the Klamath River and its tributaries.

The six mainstem Klamath River dams were all initially constructed without fish passage; therefore, anadromous fish were cut off from the Upper Klamath River reaches above the COPCO 1 dam site in 1918. They were cut off from an additional 7 miles of river, upstream of Iron Gate Dam (river mile 190) in 1962. Two primary hatcheries were established in the Klamath Basin for raising coho, Chinook, and steelhead: the Trinity River Hatchery, built in 1963, and the Iron Gate Hatchery, built in 1966 (CRS, 2005).

Although the COPCO expressed willingness to construct a single fish ladder at COPCO 1, they and the State of California agreed to close off all runs of anadromous fish and to compensate for the loss of natural runs by stocking the lakes and streams of the Klamath Basin with hatchery-raised fish. Most fishery biologists at the time did not believe fish migration over COPCO 1 via fish ladder was feasible (Beckham, 2006).

Because the SONCC ESU of coho salmon is listed as threatened under the federal ESA, the commercial harvest of these fish has been prohibited. In addition, the Chinook salmon harvest has been restricted in northern California and southern Oregon marine waters for several years to allow the Klamath River to attain the Pacific Fishery Management Council’s spawning escapement goals (CRS, 2005).

In 2006 the lack of returning adult salmon to the Klamath River resulted in the closure of several hundred miles of Pacific Coast salmon fisheries (USGS, 2007). Each summer large blooms of the blue-green algae Aphanizomenon flos-aquae in the Upper Klamath Lake lead to low dissolved oxygen and lethal conditions (in part because they produce harmful toxins) for endangered suckers. Major die-offs of suckers occurred in 1986, 1995, 1996, and 1997 (USGS, 2007).

## 1.4 Present Water and Related Resources Development

### 1.4.1 History of Settlement

Indigenous people have inhabited the Klamath River Basin since time immemorial (Beckham, 2006). Currently the basin is home to six federally recognized Indian Tribes: the Yurok Tribe; Hoopa Valley Tribe; Karuk Tribe; the Klamath Tribes, comprised of Klamath, Modoc, and Yashookin; Quartz Valley Indian Community; and Resighini Rancheria (77 FR 47868). Numerous additional native groups that are not federally recognized, such as the Shasta people, inhabit parts of Northern California and Southern Oregon. Although they are not federally recognized, some of them have been inducted into the Karuk Tribe (Beckham, 2006).

The Klamath River and canyon are considered sacred by the native tribes (Bureau of Land Management, 1990). The study area includes burial grounds of the Shasta people and their principal ceremonial areas, which are used for spiritual and educational purposes. Native tribes also value the canyon for other important cultural activities. The river area has long been used for fishing, gathering, and hunting; as a meeting place between the area's various tribes and bands; as shared fishing villages; and as a pathway for inter-tribal exchange and communication (Bureau of Land Management, 1990).

Initial Euro-American explorers in the Klamath Basin included fur traders from the Hudson Bay Company as well as surveyors from the United States Navy and Army and emigrant travelers. Settlement began in the mid-1800s, with the discovery of gold in the Lower Klamath Basin, below the Shasta River confluence (Beckham, 2006). Long-term settlement solidified with the passing of the Homestead Act in 1862, which allowed citizens (or those intending to be naturalized) over 21 years old to settle on 160 acres (or less) of land. Railroad development and logging came later due to the rugged terrain in the southern Cascades and Siskiyou Mountains (Beckham, 2006; CDWR, 1960). The Reclamation Act of 1902 initiated a number of federal irrigation projects across the western United States to manage already existing irrigation and to expand settlement in the arid west. Development of Reclamation's Klamath Project is described in Section 1.4.2. Water Resources Development.

At one time the Klamath watershed was one of the greatest timber-producing regions in the nation (CDWR, 1960). The Klamath River and tributaries were historically used to transport logs to mill sites. For example, in the late 1800s the

Klamath River Improvement Company drove logs from the Spencer Creek area (west of Keno, Oregon) to the California-Oregon state line. Splash dams made of wood and rock were historically used to create surges of water that would facilitate transportation of logs downstream (Beckham, 2006). The timber industry continues to be a significant portion of the regional economy, despite declines since the late 1970s and early 1980s.

Recreational facilities like campgrounds and trails have drawn many tourists annually into the area including Crater Lake, the Modoc Lava Beds, the Trinity Alps, Marble Mountain Primitive Areas, and the coastal redwoods (CDWR, 1960). River reaches between JC Boyle Dam and Iron Gate Dam, as well as below Iron Gate Dam, are major destinations for commercial and private white-water rafting and kayaking (CRS, 2005).

### 1.4.2 Water Resources Development

#### *1.4.2.1 Upper Klamath Basin*

The passing of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the federal government, led to the development of the Klamath Irrigation Project (Figure 1-2). The initial project was completed in 1907. By 1924 portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region (Reclamation, 2000).

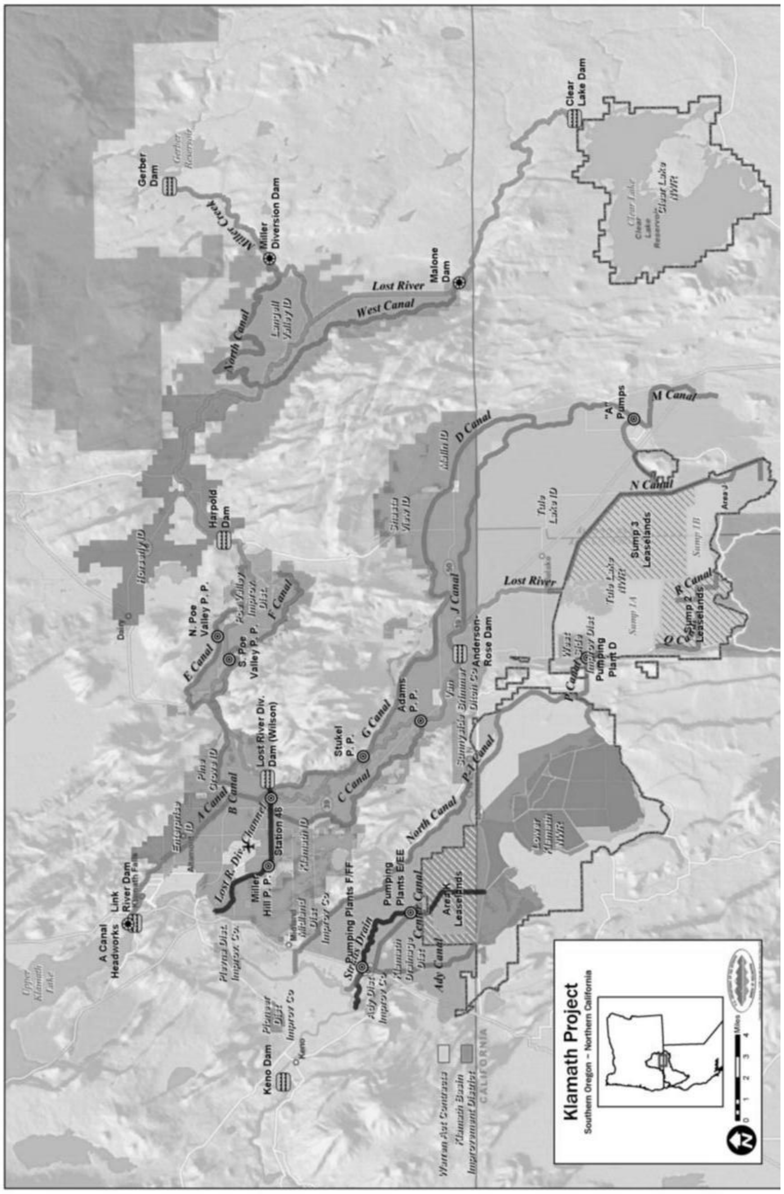


**Figure 1-2. Klamath Irrigation Project map**

Reclamation's Klamath Project is primarily fed by Upper Klamath Lake and the Lost River system, which includes Clear Lake Reservoir on the Lost River and Gerber Reservoir on tributary Miller Creek (refer to Table 1-1). Releases from Clear Lake and Gerber Reservoirs are delivered to the east side of the Klamath Project to irrigate lands in Langell Valley. The Lost River also receives water from Bonanza Springs located in Bonanza, Oregon. During the irrigation season, flows from the springs in the Lost River may be available for irrigation (Reclamation, 2012).

Prior to development of Reclamation's Klamath Project, the Klamath and Lost River Basins were linked by a flood channel, the Lost River Slough, which allowed water from the Klamath River to enter the Lost River and flow to Tule Lake during high runoff conditions. The two watersheds are now linked by the Lost River Diversion Channel, which facilitates water management and surface delivery of water to the Klamath Project, Tule Lake NWR, and Lower Klamath NWR. During the wet periods of the year water is diverted to the Klamath River; during the drier periods irrigation water is diverted to the Lost River from the Klamath River for irrigation needs (Reclamation, 2011a).

Reclamation's Klamath Project has historically included approximately 254,000 acres of land. It provides water to approximately 1,400 farms covering about 200,000 acres as well as about 27,000 irrigable acres of refuge lands. Principal crops raised on Reclamation's Klamath Project include alfalfa, irrigated pasture, small grains, and potatoes. Onions, horseradish, mint, and strawberry plants are also grown (Reclamation, 2011a; CRS, 2005). In 2011 the Klamath Project's gross crop values were estimated at $204 million (Reclamation, 2012). Water released from one of the project's storage reservoirs may be reused several times before it is returned to the Klamath River. Some of the return flows provide water to the Lower Klamath NWR and the Tule Lake NWR. Excess water and water released from NWR lands is returned to the Klamath River via the Klamath Straits Drain.

Additional irrigation in the Upper Klamath Basin occurs in Butte Valley, California, where the Butte Valley Irrigation District supplies water for approximately 4,000 irrigated acres in the southern end of the valley (CDWR, 1960).

#### *1.4.2.2 Lower Klamath Basin*

The Lower Klamath Basin also supports agriculture, but to a lesser extent than the Upper Basin. As of 1997 the number of Lower Basin farms was about 40 percent of those found in the Upper Basin, and agricultural production was estimated to be less than half the value of Upper Basin agriculture ($114 million compared to $283 million) (CRS, 2005).

There are four organized irrigation districts in the Shasta Valley (approximately 10,000 irrigated acres). The Dwinnell Dam, forming Dwinnell Reservoir, or Lake Shastina (Table 1-1), is maintained by the Montague Water Conservation District,

the largest of the Shasta watershed irrigation districts. About 24,000 acres within the Shasta Valley, but lying outside the irrigation districts, are served by individual diversions from various streams (CDWR, 1960). The only known trans-boundary diversion into the Klamath River Basin is from the Sacramento River Basin in California. About 4,000 acre-feet seasonally are diverted into the basin and used for irrigation purposes in the extreme southern end of Shasta Valley.

The Scott River Irrigation District is the single major organized water provider in Scott Valley, California. The district serves approximately 3,500 irrigated acres (CDWR, 1960). Surface water supplies for irrigation are supplemented by pumping of ground water. Most of the irrigated area in Scott Valley, however, lies to the west of the river and is supplied by individual development (CDWR, 1960).

There are additional small cultivated areas in the Lower Klamath Basin, including Hayfork Valley, a portion of the Hoopa Valley Indian Reservation on the Trinity River, and small areas in the vicinity of Lewiston and Seiad Valley (CDWR, 1960).

The Trinity River, the lowermost tributary of the Klamath River, provides water to the California Central Valley Project (CVP), another federal project (CRS, 2005). The Trinity River Division of the CVP was completed in 1964. The Trinity River is the largest tributary of the Klamath River. It enters the Klamath River about 20 miles upstream of its mouth at the Pacific Ocean. The Trinity River Diversion diverts and exports water from the Trinity River system by means of dams, reservoirs, tunnels, and power plants to the Sacramento River (CRS, 2005). At one time, nearly 90 percent of the water in the Trinity River was exported to the Central Valley (CRS, 2005). However, a 2000 Record of Decision reduced that percentage to restore fisheries (CRS, 2005). Lewiston and Trinity Dams (refer to Table 1-1) had cut off 109 miles of anadromous fish habitat on the Trinity River (CRS, 2005).

There are two additional trans-boundary diversions from the Klamath Basin, both in the western portion of the Upper Klamath Basin. One diversion is made from Keene Creek by way of Hyatt Prairie Reservoir, and the other diversion is made from Fourmile Creek by way of the Cascade Canal. This diverted water supplies irrigate lands adjacent to Ashland and Medford in the Rogue River Basin (CDWR, 1960).

### 1.4.3 History of Water Management Challenges

The Klamath River Basin, like many watersheds in the arid western United States, suffers from use beyond the sustainable capacity of the basin (i.e., over-appropriation). This may be due to a number of factors. First, there are physical constraints in the watershed that are unique to the Klamath Basin. Second, federal and state policies with respect to indigenous people and the environment have not been consistent over time, which has contributed to complex

socioeconomic challenges. Finally, regulatory constraints exist in terms of conflicting state and federal policies. This section will briefly describe these constraints as a way of identifying historical and current water management challenges in the basin and to emphasize the need for a comprehensive Klamath River Basin Study to evaluate any identified current and/or projected future imbalances in water supply and demand.

The Klamath River Basin is unique in that the largest agricultural development in the basin occurs in the Upper Klamath, which receives disproportionately low precipitation compared with the rest of the basin. The Upper Klamath Basin has limited suitable sites for reservoir storage; therefore, water users are subject to the effects of climate variability. For example, Upper Klamath Lake, which is the primary source of water for Reclamation's Klamath Project, is relatively shallow and has little carryover storage from year to year, which makes the project highly dependent on current precipitation and snowmelt for water supply (CRS, 2005).

Implementation and enforcement of state and federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for applications for higher use of water supplies over applications for lower use supplies, defined as recreation, industrial, hydropower, and other uses. Water rights adjudication in California was completed for the Shasta River Basin in 1932 and for the Scott River Basin in 1980, but the mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin. Lower Klamath NWR and Tule Lake NWR rely on water from Reclamation's Klamath Project. These refuges have received lower priority for water than irrigators. However, the Lower Klamath NWR (established in 1908) may have federal reserved rights which would advance their priority (CRS, 2005).

Endangered species issues have been an integral component of operating decisions for Reclamation's Klamath Project since the USFWS listed the shortnose and Lost River suckers as endangered in 1988 and the NMFS listed the SONCC ESU coho salmon as threatened in 1997 (CRS, 2005). Management

challenges associated with opposing water needs and policies are illustrated by the events that took place in the early 2000s (described briefly below), which resulted in the largest fish die-off ever recorded in the Klamath River and severe curtailment of irrigation deliveries to Klamath Project irrigators, resulting in economic hardship.

Reclamation is required to comply with the ESA by consulting on the ongoing operations of the Klamath Project with the USFWS and NMFS (the agencies with delegated authority to implement the ESA) to ensure that its operations do not jeopardize listed species or listed or proposed critical habitat. The USFWS has jurisdiction over inland fish and terrestrial species (shortnose sucker, Lost River sucker, and proposed critical habitat for both sucker species). The NMFS has jurisdiction over marine species and anadromous fish (e.g., SONCC ESU coho salmon). In early 2001 a federal district court faulted Reclamation for failing to formally consult with NMFS on the effects of water storage and diversion on downstream coho salmon under its 2000 operating plan, and prohibited Reclamation from making further diversions until it formally consulted on its next (2001) annual plan. Reclamation prepared an operation plan for 2001 which was forecast to be one of the driest years of record. Reclamation prepared a biological assessment (February 13, 2001) which covered operations until April 1, 2001. In April 2001, the USFWS and NMFS each issued final Biological Opinions concluding that Reclamation's proposed operation of the Klamath Project for 2001 would jeopardize the two species of suckers and the population of coho salmon, and it would harm, but not jeopardize, the continued existence of bald eagles. NMFS recommended release of additional water from Upper Klamath Lake for coho salmon, while USFWS simultaneously recommended maintaining higher lake levels. Because of severe drought conditions, there was not enough water to implement both Biological Opinions simultaneously, even without providing irrigation water for farmers. A judge's order prevented Reclamation from fulfilling water orders under contracts to the irrigators whenever flows dropped below the minimum flows recommended in the 2001 NMFS Biological Opinion (Reclamation, 2011e).

Reclamation announced its response on April 6, 2001, implementing proposed alternatives that severely limited the delivery of irrigation water. For the 2001 water year, Reclamation stated that the normal deliveries would be available for lands receiving water from Clear Lake and Gerber Reservoirs (70,000 to 75,000 acre-feet), but no water would be available from Upper Klamath Lake for deliveries to irrigators or to the Lower Klamath NWR (CRS, 2005). Water conservation measures and higher than expected lake levels later in the summer prompted the Secretary of the Interior to announce that up to 75,000 acre-feet would be released from Upper Klamath Lake to assist farmers. However, this came too late in the season to provide significant assistance.

The National Research Council reviewed the scientific decisions of the controversial 2001 Biological Opinions. The National Research Council Committee concluded that scientific data were insufficient to support the Upper

Klamath Lake level management regimes proposed by the 2001 USFWS Biological Opinion. Although Reclamation's written response to the USFWS 2001 Biological Opinion expressed disagreement with the Biological Opinion's conclusions, Reclamation agreed to not deliver any water from Upper Klamath Lake to Klamath Project water users and NWRs from April through September 2001. Water from Gerber and Clear Lake Reservoirs was used for irrigation on and to meet evaporative losses on the NWR. Releases from Upper Klamath Lake were made to meet minimum stream flows; however, the project was operated to modified minimum elevations for Upper Klamath Lake, which deviated from the minimums prescribed in the USFWS Biological Opinion. An above average number of Chinook salmon entered the Klamath River that August and September, while river flows were unusually low due to drought conditions and unusually warm temperatures. These conditions contributed to the death of more than 33,000 adult salmon (primarily Chinook but also coho, steelhead, and others) due to epizootic disease in the first 40 miles of the river (California Department of Fish and Game, 2004; CRS, 2005).

Several ESA consultations since the early 2000s have affected Klamath Project operations. The most recent to date (and to which current operations adhere) is the 2012 Biological Assessment and 2013 Biological Opinion (BiOp) jointly prepared by the USFWS and NMFS on the Lost River and shortnose sucker, the SONCC coho salmon, the Southern distinct population segment (DPS) green sturgeon, and the Southern DPS eulachon, which directs the operations throughout the Upper Klamath Basin and influences river flows from Link River Dam to the Klamath Estuary. The Biological Assessment and Joint BiOp were completed following a multi-year consultation effort between Reclamation, the USFWS, and NMFS to develop a new long-term operations plan that would "allow Reclamation to continue to operate the Klamath Project to store, divert, and convey water to meet authorized Klamath Project purposes and contractual obligations in compliance with applicable state and federal law while meeting the conservation needs of affected listed species in a coordinated manner" (NMFS and USFWS, 2013).

## 1.5 Future Challenges and Considerations

The Klamath River Basin Study identifies and evaluates potential adaptation strategies to reduce any identified water supply/demand imbalances. Numerous studies have already identified and investigated potential adaptation strategies. To the extent possible, this study builds upon past or existing efforts and encompasses a wide range of options, perhaps even previously rejected strategies that may perform differently under a wider range of evaluation measures.

This study must also consider the regulations that are in place or in progress in the basin, including among other things total maximum daily load (TMDL) water quality criteria established in parts of the watershed, as well as past and existing restoration efforts. For example, this study considers, in a scenario context, the

ongoing negotiations of the Klamath Basin Restoration Agreement (KBRA) and Klamath Hydropower Settlement Agreement and the related Secretarial Determination Process. The following section of this report touches on these considerations in more detail and concludes with recognition of future challenges.

### 1.5.1 Previously Identified Management Alternatives

Numerous studies have been initiated to investigate options for increased or new storage (including groundwater), demand reduction, and habitat restoration, even before the events of 2001 and 2002. The Klamath Basin Water Supply Enhancement Act of 2000 (P.L.106-489) authorized Reclamation to study the feasibility of increasing storage capacity in the Upper Klamath Basin and Reclamation's Klamath Project through surface or groundwater supplies (CRS, 2005). Potential options were identified and developed in the 1990s through the Klamath Basin Water Supply Initiative, a public input process involving potentially affected state, local, and tribal interests as well as concerned stakeholders (for example, potential new storage in the Long Lake Valley [Reclamation, 2010]). The Initial Alternatives Information Report, Upper Klamath Basin Offstream Storage Study (Reclamation, 2011a) further investigated options including an aquifer storage and recovery groundwater option at Gerber Reservoir and a hybrid option involving aquifer storage and recovery at Clear Lake and surface storage at a new dam (to be named Boundary Dam). However, these investigations have not identified viable options from a cost/benefit perspective.

Water banking has also been proposed as a management strategy. During the water shortage of 2001, Reclamation initiated the Groundwater Purchase Program, a water bank to buy water for fish and wildlife (CRS, 2005). As part of the NMFS 2002 Biological Opinion, Reclamation could avoid jeopardizing ESA threatened coho salmon by creating and implementing a water bank. Eligible farmers could bid to irrigate their lands with groundwater from their own wells in exchange for payment, thereby freeing water from Upper Klamath Lake (CRS, 2005). These pilot water bank programs were successful in meeting NMFS Biological Opinion requirements for the 2003 and 2004 water years. Reclamation employed a combination of land idling and groundwater substitution in an attempt to meet water banking targets for 2005–2011; however, in 2006 the court eliminated the water banking requirement that was part of the NMFS 2002 Biological Opinion (Reclamation, 2011). Groundwater pumping has also been identified as a potential long-term water management strategy. Pumping groundwater provides short-term benefits, but over-drafting of aquifers has long-term consequences that are less clear (CRS, 2005).

A number of entities are undertaking specific projects to improve water quality and restore habitat. For example, the U.S. Department of Agriculture's Natural Resources Conservation Service has a Work Plan for Adaptive Management for the Klamath Basin to mitigate the effects of drought on agriculture. The core objectives of this program are: (1) decreasing water demand, (2) increasing water storage, (3) improving water quality, and (4) developing fish and wildlife habitat.

### 1.5.2 Development of Water Quality Criteria

Criteria for TMDLs have been established for the Klamath River Basin (including Lost River) through collaboration between the California North Coast Regional Water Quality Control Board, Oregon Department of Environmental Quality, U.S. Environmental Protection Agency (EPA) Regions 9 and 10, and contractors. The TMDLs for the mainstem Klamath River (including an implementation plan for the already approved Lost River TMDL) were approved by the California State Water Resources Control Board and EPA Region 9 in December 2010. NMFS completed its ESA consultation on the Klamath River TMDLs in December 2010 (National Oceanic and Atmospheric Administration [NOAA], 2011). The Oregon Department of Environmental Quality issued a departmental order adopting TMDLs for the listed parameters for the Upper Klamath (Link River Dam to California state line) and the Upper Lost River. The Oregon TMDLs have been submitted to EPA Region 10 for final approval. TMDLs for the Klamath River's major tributaries (Lost, Scott, Shasta, and Trinity Rivers) were previously established. Klamath River Basin TMDLs are summarized in Table 1-2. When TMDLs are developed, water quality criteria are established for sustaining fish and wildlife species, then acceptable waste load allocations are identified. In many cases existing natural conditions exceed established water quality criteria.

**Table 1-2. Summary of Klamath Basin TMDLs**

| Sub-basin or Reach | TMDL |
|---|---|
| Sprague River, Williamson River, Upper Klamath Lake | Dissolved oxygen, chlorophyll a, pH (2002) |
| Lower Lost River (Oregon) | Dissolved oxygen, pH, ammonia toxicity, temperature in Lost River tributaries (2010) |
| Lower Lost River (California) | Nutrients, pH (2008)<br>Temperature (2006) |
| Klamath River (Oregon) | Dissolved oxygen, pH, ammonia toxicity, temperature, chlorophyll a (2010) |
| Klamath River (California) | Nutrients, temperature, dissolved oxygen/organic enrichment (2010) |
| Shasta River | Temperature, dissolved oxygen (2007) |
| Scott River | Temperature, sediment (2006) |
| Salmon River | Temperature (2005) |
| Trinity River | Sediment (2001) |

*Source: EPA, 2008*

### 1.5.3 Past or Existing Restoration Efforts

Numerous programs have been established in an effort to restore natural function of the Klamath River, to the extent possible, and to encourage recovery of the basin's ESA listed species. This section highlights some of these activities; however, it does not attempt to identify all past and present planning activities.

The Klamath River Basin Fishery Resources Restoration Act of 1986 established the Klamath Fishery Management Council to monitor the fish population and recommend annual fish harvest limits, as well as the Klamath River Basin Fisheries Task Force to advise the Secretary of Interior regarding implementation of the Restoration Program (U.S. Government Accountability Office, 2005). A USFWS office was established in Yreka, CA in 1987 to facilitate implementation and management of the Restoration Program (U.S. Government Accountability Office, 2005). However, due to funding constraints the Restoration Program was left to expire in 2006.

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 required the NMFS to develop a recovery plan for SONCC ESU coho salmon in 2007 (NOAA, 2011). Since the early 1990s, harvesting of the Klamath River fall-run Chinook salmon stock was restricted offshore from California and Oregon due to low returns. However, based on recent increases in naturally spawning adults, the Secretary of the Interior declared Klamath River fall Chinook salmon populations restored in 2011 (NOAA, 2011).

Additional restoration and recovery actions include construction and monitoring of off-channel ponds (initiated in 2010) to address limited winter rearing habitat for ESA-listed coho salmon. Monitoring efforts following construction showed more than 250 juvenile coho salmon moving into the new ponds in Terwer Creek, illustrating the importance of this habitat for overwintering coho salmon. In 2010 NOAA's Open Rivers Initiative provided funding to the Shasta River Fish Passage Project for removal of the Grenada Irrigation District diversion dam. The Nature Conservancy continues to work on the Shasta River Big Springs Creek to restore more than 11 miles of salmon and steelhead spawning and rearing habitat.

The Trinity River Flow Evaluation (USFWS and Hoopa Valley Tribe, 1999) recommended a restoration strategy for the Trinity River that integrates restoration of riverine processes with the instream flow-dependent needs of salmonids. As a result, the Trinity River Restoration Program strives to restore the natural physical processes in the river and create spawning and rearing conditions (including adequate water temperatures) downstream of the dams that best compensate for lost habitat upstream (Trinity River Restoration Program, 2009).

The federal Wetlands Reserve Program is one of several programs implemented by the U.S. Department of Agriculture. Since the program's inception in 1990, it has resulted in the restoration of approximately 30,400 acres of wetlands in Oregon's Upper Klamath River Basin (Duffy et al., 2011).

Some major Reclamation actions to conserve native fish include construction of a fish screen on the A-Canal, completed in 2003; completion of the Link River Dam fish ladder in 2005; numerous monitoring and research studies; and the removal of Chiloquin Dam on the Sprague River to allow suckers access to historic spawning areas in 2008. The USFWS maintains a habitat restoration program and activities on the NWRs, including walking wetlands. The Nature Conservancy restored 7,000 acres of wetlands at the Williams River Delta of Upper Klamath Lake.

#### *1.5.3.1 Klamath Basin Restoration Agreement and Klamath Hydroelectric Settlement Agreement*

A large coordinated Klamath Basin restoration planning effort involving 42 Klamath Basin stakeholders began in 2007 and was completed in 2010. The resulting agreement, the KBRA, takes a multi-dimensional approach that attempts to resolve complex problems by focusing on species recovery while recognizing the interdependence of environmental and economic problems in the Basin's rural communities (Klamath Settlement Group, 2009a). The goals of the KBRA include:

- Restoring and sustaining natural production and providing for full participation in ocean and river harvest opportunities of fish species throughout the Klamath Basin

- Establishing reliable water and power supplies which sustain agricultural uses, communities, and NWRs

- Contributing to the public welfare and the sustainability of all Klamath Basin communities

The KBRA was intended to be implemented alongside the Klamath Hydroelectric Settlement Agreement (KHSA), which lays out the process for conducting necessary additional studies, environmental reviews, and a decision by the Secretary of the Interior (called Secretarial Determination) surrounding the possible removal of the lower four dams on the Klamath River owned by PacifiCorp beginning in 2020. These dams are Iron Gate, COPCO 1, COPCO 2, and J.C. Boyle. The KHSA includes provisions for the interim operation of the dams prior to dam removal, the process to transfer, decommission, and remove the dams, and the transfer of Keno Dam to the Department of the Interior (Klamath Settlement Group, 2009b). On December 31, 2015 the KBRA terminated because federal authorizing legislation was not enacted. The KHSA is still in effect but its interdependent connection to the KBRA requires its amendment to continue. On February 2, 2016 an agreement-in-principle to amend the KHSA was announced between the states of Oregon and California, PacifiCorp, and the US Departments of Interior and Commerce. The ultimate timing of its implementation is not currently known, but the KHSA describes the implementation of the dam removal action in 2020.

A joint National Environmental Policy Act/California Environmental Quality Act (NEPA/CEQA) analysis has been performed and a final Environmental Impact Statement/Environmental Impact Report containing 18 alternatives has been completed. Five of the alternatives, including the no project/no action alternative, were carried forward for detailed evaluation. Among the five alternatives carried forward is full implementation of the KHSA and KBRA (Interior and the California Department of Fish and Game, 2011; Thorsteinson et al., 2011).

### 1.5.4 Future Challenges

The primary challenge of the Klamath River Basin Study is determining how to address the uncertainties related to water management in the basin. For example, the fate of the KBRA and KHSA is unknown at this time. Quantification of potential imbalances in current and projected future supply and demand and subsequent evaluation of identified management strategies would yield vastly different outcomes, depending on whether the four lower Klamath River dams are removed and associated restoration efforts move forward. To address this future challenge, the Klamath River Basin Study takes a scenario approach in order to increase flexibility in evaluating climate change impacts on the baseline system.

## 1.6 Collaboration and Outreach

The Klamath River Basin Study is a collaborative effort involving Reclamation and two non-federal cost share partners, the CDWR and the OWRD. The study seeks additional tribal and stakeholder involvement through a process described in the Public Participation and Outreach Plan. The Public Participation and Outreach Plan describes the tribal, stakeholder, and public participation process; however, an overview is provided in this chapter. The process of involving tribes and stakeholders is likely to evolve: consequently the plan will be adapted, as needed, as the study gets underway.

The Klamath River Basin Study was guided by a technical working group (TWG), with input from interested organizations and individuals. The non-federal cost share partners (CDWR, OWRD, and Reclamation) comprise the TWG, which was the primary decision making body for the Basin Study and which conducted a peer review of technical deliverables. Interested organizations and individuals were asked to provide input on the study approach and findings throughout the process. These groups or individuals included federal, state, and local governments; tribes; water use organizations; and non-profit groups. The general public was kept apprised of the progress and findings of the Basin Study primarily through existing public meetings that took place across the region. Figure 1-3 illustrates the Basin Study organization.

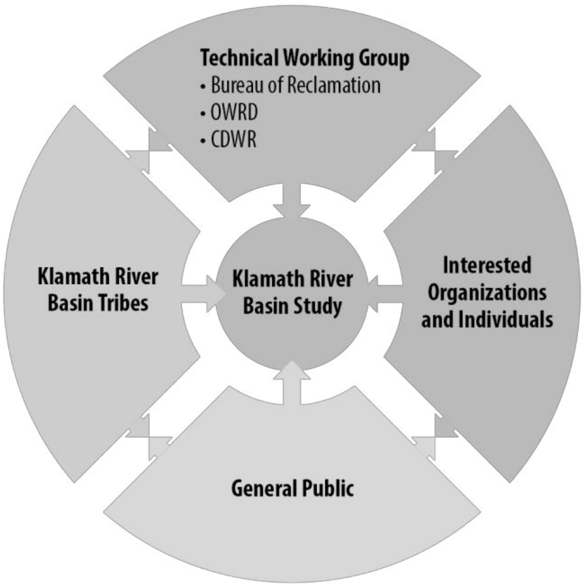


**Figure 1-3. Klamath River Basin Study organizational chart**

## 1.7 What to Expect in this Study

The Klamath River Basin Study, consistent with the Basin Study Framework (Reclamation, 2009), contains four primary components. These are listed in Section 1.2, Purpose, Scope, and Objectives of the Study. They are also illustrated in Figure 1-4, which provides an overview of the basin study approach, highlighting Chapter 1. The first component of the Klamath River Basin Study includes an assessment of current and projected future water supplies. Projected scenarios of future water supply are drawn from methods described by WWCRA (Reclamation, 2011d). However, this study also incorporates climate scenarios from the Coupled Model Intercomparison Project, Phase 5 (CMIP5) (Taylor et al., 2012). The Klamath River Basin Study also utilizes streamflow reconstructions from tree-rings to provide a greater variability context for historical climate and hydrologic conditions. This portion of the study evaluates past and projected future changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater if possible.

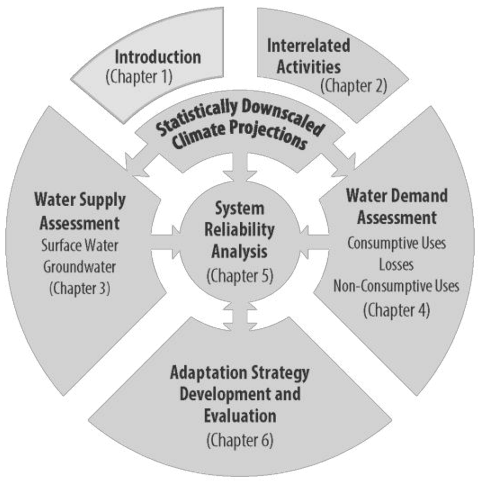


**Figure 1-4. Overall approach for Klamath River Basin Study, highlighting Chapter 1**

The second component of the Klamath River Basin Study includes an assessment of current and projected future water demands. The assessment includes quantification of historical and projected future agricultural demands and open water evaporation. This study takes advantage of newly available demand information through the WWCRA.

The third component of the Klamath River Basin Study includes evaluating the watershed's ability to meet or withstand any identified future water supply/demand imbalances (these may include infrastructure, fish and wildlife, etc.). System reliability is determined by testing the system against various defined performance measures. These measures were developed with input from the Klamath River Basin Study TWG and interested organizations and individuals. This component relies heavily on projections from the first two components of the study (assessment of current and projected future water supply and demand). The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions.

The fourth and final component of the Klamath River Basin Study includes identifying and quantifying potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Adaptation strategies include a range of concepts including operational changes or habitat restoration, among others. In general, the study aimed to identify potential adaptation strategies that that have the potential for reducing water supply/demand imbalances that are likely as a result of climate change.

Adaptation strategies are evaluated using a decision-making framework. Chosen strategies in the Klamath River Basin Study were general in nature in order to evaluate the sensitivity of the basin's water resources to different types of strategies.

The goal for the Klamath River Basin Study is to provide added value to past and ongoing studies to work toward meeting the needs of water users and fish and wildlife in the basin. Further, the Basin Study provides a holistic view of the entire Klamath watershed and does not discount any recommended adaptation strategies. All adaptation strategies identified through the stakeholder and public participation process are included as Appendix E to the Klamath River Basin Study final report.

## 1.8 Supporting Information

The literature synthesis, along with a list of corresponding references, is provided as Appendix A.

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# Chapter 2
# Klamath River Basin Study
# Identification of Interrelated Activities

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# Contents

# Figures

# Chapter 2
# Identification of Interrelated Activities

The Klamath River Basin is unique in that its natural setting and inherent challenges require cooperation among all levels of government and organization. The Klamath River Basin is an interstate watershed with six federally recognized tribes. Three ESA listed fish species are directly affected by water use, and these are being managed by a combination of federal, state, and local efforts. The variety of groups with management responsibilities in the basin has resulted in numerous interrelated activities and coordinated efforts. Following is a brief description of interrelated activities in the Klamath River Basin that are relevant to the Klamath River Basin Study. Also, Figure 2-1 illustrates how Chapter 2 fits into the overall basin study approach.

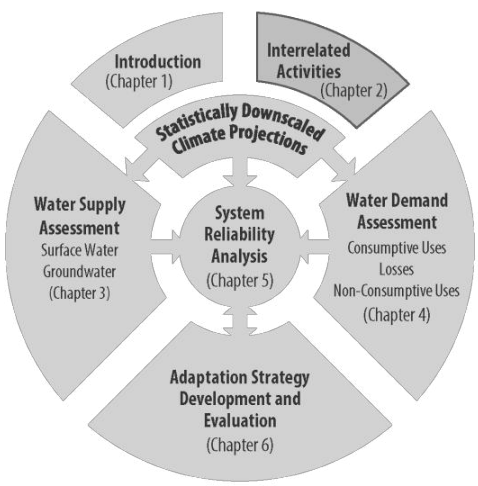


**Figure 2-1. Overall approach for Klamath River Basin Study, highlighting Chapter 2**

## 2.1 Federal

Because the Klamath River Basin contains two federal irrigation projects (Reclamation's Klamath Project and a part of the Trinity River Division), provides habitat for species listed as threatened or endangered under ESA, contains one national park (Crater Lake National Park) and thousands of acres of National Forest and Bureau of Land Management Lands, plus is home to six federally recognized native tribes, numerous past and ongoing federal activities overlap and have common goals. The primary common thread that brings various agencies and activities together is the effort to recover three of the basin's seven ESA listed fish species: the SONCC ESU coho salmon (threatened) and Lost River and shortnose suckers (endangered).

Reclamation's Klamath Project first began providing water to irrigators in 1907, and since then the project has grown to about 254,000 acres of land. The Upper Klamath Basin hydrologic system was significantly altered as a result of:

- wetlands drained from Upper and Lower Klamath and Tule Lakes
- construction of dams and conveyance structures by Reclamation
- construction of seven hydroelectric facilities by PacifiCorp
- a Bureau of Indian Affairs dam on the Sprague River, subsequently removed by Reclamation in 2008
- other water diversions and withdrawals above the Klamath Project

Development in the Klamath River Basin over the last century, including construction of dams without fish passage facilities, has caused declines in anadromous and resident fish species. Their decline was recognized in the early 1980s with passage of the Klamath River Basin Fishery Resources Restoration Act (P.L 99-552), which established the Klamath Basin Restoration Fisheries Task Force and charged it with developing a 20-year Klamath River Basin Conservation Area Fishery Restoration Program. This program was allowed to expire in 2006 and no longer operates; however, numerous restoration projects were implemented over the 20-year period.

Since the listing of three Klamath River Basin fish species under ESA, Reclamation has worked with the NMFS (responsible for SONCC ESU coho salmon) and the USFWS (responsible for Lost River and shortnose sucker) on Klamath Project operations plans that reduce regulated flow impacts to these species (Reclamation, 2011f; Reclamation, 2012a). Due to low water availability in 2001, Reclamation was not able to meet irrigation needs or recommended Klamath River flows and Upper Klamath Lake levels for the ESA listed species. As a result, the National Research Council (charged with advising the federal government on science issues) was directed to review the science underlying

recommendations by the NMFS and the USFWS (National Research Council, 2002; National Research Council, 2004; National Research Council, 2008).

In an interim report completed in 2002, the National Research Council concluded that the recommendations had substantial scientific support except for those regarding minimum lake levels of Upper Klamath Lake and increased minimum flows in the mainstem Klamath River. Also, it found Reclamation's Klamath Project operations would not affect tributary conditions, which were deemed the most critical for species survival. At the same time, the National Research Council found Reclamation's proposed minimum Klamath River flows would result in an unknown risk to the population.

In their final report in 2004, the National Research Council corroborated their interim findings and, in addition, provided a broad set of recommendations for the recovery of threatened and endangered species in the entire basin, including expanding the scope of ESA actions by the NMFS and USFWS, planning and organizing research activities and monitoring, identifying specific high priority recovery actions for endangered suckers (e.g., removal of Chiloquin Dam which occurred in 2008), identifying information needs related to SONNC ESU coho salmon, and identifying remediation measures that could be implemented based on current information.

Reclamation has conducted numerous studies with the overarching goal of reducing the Klamath Project impacts on the natural river system. These studies include efforts to evaluate potential new off-stream storage facilities, groundwater pumping and aquifer storage options, and water banking mechanisms. Examples of these studies include the Long Lake Valley appraisal report (Reclamation, 2011a), the Upper Klamath Basin Offstream Storage Investigations, Initial Alternatives Information Report (Reclamation, 2011e), the Klamath Project Yield and Water Quality Improvement Options Appraisal Study (Reclamation, 2012e), and the KBRA On-Project Plan (Klamath Water and Power Agency, 2011).

Other federal agencies have also undertaken numerous activities with the goal of managing natural resources for the livelihoods of Klamath River Basin residents while maintaining, as much as possible, the natural ecosystem critical for ESA listed species and others. The Bureau of Land Management (BLM) has conducted watershed analyses for the mainstem Trinity River (BLM, 1990), for which the goal was to compile existing knowledge about various physical processes important in the basin and work toward more holistic ecosystem management. The BLM was also involved in the process to classify reaches of the Klamath River and its tributaries in the National Wild and Scenic Rivers System (BLM, 1990).

The U.S. Forest Service (USFS) conducted a watershed analysis for the Six Rivers National Forest (Orleans Ranger District) in 2003 to support potential watershed restoration actions related to the recovery of ESA listed anadromous salmonid fish species, and to implement fuels reduction around local

communities, municipal water sources, and private lands as outlined by USFS fire plans (USFS, 2003). The Six Rivers National Forest intersects part of the Lower Klamath Basin. The USFS also completed a land and resource management plan (USFS, 1995) for the Six Rivers National Forest, which takes into account impacts to the ESA listed species.

The USFWS and NMFS work cooperatively with private entities to produce habitat conservation plans for incidental take of fish and wildlife species. The USFWS has also been involved in Trinity River Restoration Program efforts to improve the natural function of the Trinity River below Lewiston Dam. For example, they completed the Environmental Impact Statement/Environmental Impact Report (EIS/EIR) (USFWS et al., 2000) on the Trinity River Flow Evaluation Study, which resulted in the December 19, 2000 Record of Decision to establish the Trinity River Restoration Program (Interior, 2000).

The NMFS has been involved in a wide variety of interagency efforts, including the development of the SONCC ESU coho salmon recovery plan and working with the North Coast Regional Water Quality Control Board to develop TMDLs for the Klamath River in California. The NMFS has also been involved in a number of habitat restoration projects including construction of off-channel ponds by the Mid-Klamath Watershed Council and Karuk Tribe, and installation of a series of boulder step pools to replace gravel push-up dams in a partnership between Scott Valley Resource Conservation District and local landowners (NMFS, 2009; NMFS, 2011).

The KBRA and KHSA are companion agreements between federal agencies, Klamath Basin Tribes, irrigators, fishermen, conservation groups, counties, the states of Oregon and California, and dam owners, which aim to restore Klamath River Basin fisheries and sustain local economies. The agreements include:

- removal of four dams in the upper Klamath River
- increased flows for fish
- greater reliability of irrigation water deliveries
- reintroduction of salmon above the dams and into and above Upper Klamath Lake
- investment in comprehensive and coordinated habitat restoration
- a power program for Klamath River Basin farmers and ranchers
- mitigation to counties for the effects of dam removal
- investment in tribal economic revitalization

Current Federal Energy Regulatory Commission (FERC) licenses for the dams expired in 2006. These facilities are now operated on annual licenses using existing operating plans. FERC continues to participate in the ongoing process to determine the fate of the dams.

## 2.2 Tribal

Tribal activities in the watershed include the Klamath Basin Tribal Water Quality Work Group, which conducts coordinated surface water sampling activities and participates in the Klamath River Basin monitoring program. The Klamath Basin Monitoring Program is a multi-agency organization aiming to implement, coordinate, and collaborate on water quality monitoring and research throughout the Klamath Basin. As an example, Reclamation and the Klamath Tribes have together been collecting water quality data in Upper Klamath and Agency Lakes since 1988.

The Karuk Tribe and the USFS have coordinated on the land management of the Katimiin Cultural Management Area near Somes Bar, California. Management strategies outlined are consistent with both Karuk cultural environmental management practices and the Klamath National Forest Land and Resource Management Plan. The Katimiin Cultural Management Area is where the Tribe's Pikyawish, or World Renewal, ceremonies are concluded each year (CDWR, 2013).

Three of the six federally recognized tribes in the Klamath River Basin have supported the KBRA and KHSA agreements (Klamath Settlement Group Communications Committee, 2009a, b). Although the others also strive for ESA listed species recovery and return of the Klamath River to a more natural condition, some have expressed the position that dam removal would occur more immediately if left to the FERC relicensing process.

The Hoopa Valley Tribe worked alongside Interior to lead the Trinity River Restoration Agreement, which aims to mitigate the detrimental effects of decades of out of basin diversions of Trinity River water to Reclamation's Central Valley Project (USFWS et al., 2000). The Hoopa Valley Tribe worked with the USFWS to complete the Trinity River Flow Evaluation Study, which became the basis for the Trinity River Restoration Agreement (USFWS and Hoopa Valley Tribe, 1999). The Yurok Tribe is also a member of the council governing the Trinity Restoration Agreement.

The tribes in the Klamath River Basin have also conducted or commissioned their own studies to quantify the needs of environmental resources on which they depend. For example, Trihey and Associates, Inc. (1996) sought to quantify the monthly flow requirements of Tribal Trust fish species in the mainstem Klamath River between Iron Gate Dam and the river mouth.

## 2.3 Interstate (including regional)

California and Oregon have coordinated on several activities involving the Klamath River, which flows between the states. The Klamath River Basin Compact was ratified by the states of Oregon and California in April 1957. The compact was meant to facilitate and promote the orderly, integrated, and comprehensive development, use, conservation, and control of Klamath River water for various purposes. Uses include domestic, irrigation, protection, and enhancement of fish and wildlife, industrial, hydroelectric power production, navigation, and flood prevention.

In addition to water quantity and timing, California and Oregon have coordinated on water quality issues with respect to the development of TMDLs for the mainstem Klamath River and its tributaries. The California North Coast Water Quality Control Board and the Oregon Department of Environmental Quality coordinated on completion of draft TMDLs for respective parts of the mainstem river by 2010. These are both complete and await approval.

PacifiCorps's hydropower facilities in the Klamath River Basin reside in both California and Oregon. As such, California and Oregon have undertaken studies to evaluate effects of these facilities on the environment, as well as potential effects of removal of the dams. For example, the California Coastal Conservancy (2006) evaluated sediment supplies under potential dam decommissioning scenarios.

## 2.4 State

The Klamath River Basin spans parts of California and Oregon and both states have been involved in management and planning efforts in the basin. In California, the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) aims to act as a nexus between statewide planning efforts and local planning, helping to synchronize the large, complex planning processes, regulations, and priorities at the state level with the locally specific issues, data, concerns, planning, and implementation needs at the local level.

The OWRD and CDFW (which prior to January 2013 was the California Department of Fish and Game) have collaborated with federal agencies and tribes on a number of studies. For example, the Instream Flow Study Phase II (Hardy et al., 2006) for the Klamath River, which was developed to help determine flow needs of ESA listed fish species, was a collaborative effort involving Utah State University, the USFWS, the NMFS, the USGS, the Bureau of Indian Affairs, Reclamation, CDFG, OWRD, the Karuk Tribe, the Hoopa Tribe, and the Yurok Tribe. In another example, the USGS and OWRD collaborated in a study to characterize regional groundwater in the Upper Klamath Basin and develop a groundwater flow model to test management options (Gannett et al., 2007).

### 2.4.1 Relationship to State Law including State Water Plan

Water rights adjudications in California and Oregon are in different stages of completion. The Shasta Valley in California was adjudicated in 1932, the Scott Valley in California in 1980. The mainstem Klamath River in California has not been adjudicated. The adjudication process for the Upper Klamath Basin in Oregon is ongoing, and in March 2013 the Final Order of Determination was delivered to the Klamath County Circuit Court demarking a significant milestone in determining the water rights of the Upper Klamath Basin. The adjudication covers all claims to the use of surface water that predate Oregon's 1909 Water Code. It also covers those referred to as "federal reserved water right" claims. The Circuit will now handle the remaining administrative process prior to issuance of a Court Decree. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the "time immemorial", which may significantly affect water management in the Upper Klamath Basin. The Klamath Tribes have currently agreed not to exercise their rights prior to August 9, 1908. Another significant finding of the Final Order of Determination granted co-ownership of Klamath Project water rights to both Reclamation and Klamath Project water users.

California's water plan update (CDWR, 2013) includes a discussion of activities through the North Coast Integrated Regional Water Management Plan (North Coast Regional Partnership, 2007) as well as a discussion of overall planning activities in the Klamath River Basin. However, most planning activities are carried out by federal agencies and coordinated groups.

Oregon completed its water resources strategy in 2012 and the state legislature has directed that this plan be updated every 5 years (OWRD, 2012). The plan discusses general recommendations for additional groundwater investigations, improved water monitoring, and continued research on the implications of climate change. Like California, Oregon does not direct planning activities in the Klamath River Basin as these are primarily carried out by interagency consortia.

## 2.5 Local

There are numerous local landowner and water user groups within the Klamath River Basin and many of these interact with interagency planning efforts. One example is the KBRA/KHSA planning process, which involves 42 stakeholder groups including local water managers and land owners. Also, the Klamath Basin Rangeland Trust, a nonprofit organization with the mission of improving water availability in the Upper Klamath Basin, was formed in 2002. The Trust facilitates partnerships between private landowners and public agencies to conserve water resources and restore habitat and wetlands.

Local groups are also involved in the Trinity River Restoration Planning efforts, as many of the restoration projects take place using local resources and expertise. For example, the Coordinated Resource Management Plan Group for the South

Fork Trinity River is a consortium of local landowners and various agencies who are interested in water conservation, habitat improvement, and educational outreach in the South Fork Trinity River. The group is funded by the Trinity River Restoration Program. Also, in coordination with the NMFS, Scott Valley Resource Conservation District and local landowners installed a series of boulder step pools to replace gravel push-up dams in the basin.

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# Chapter 3
# Klamath River Basin Study
# Assessment of Current and Future Water Supply

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# Contents

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# Chapter 3
# Assessment of Current and Future Water Supply

## 3.1 Introduction

The purpose of the Klamath River Basin Study is to identify current and projected imbalances in water supply and demand across the entire Klamath River Basin, and to develop and analyze adaptation strategies to help resolve any identified imbalances. A system diagram illustrating the primary components of the Klamath River Basin Study is provided in Figure 3-1.

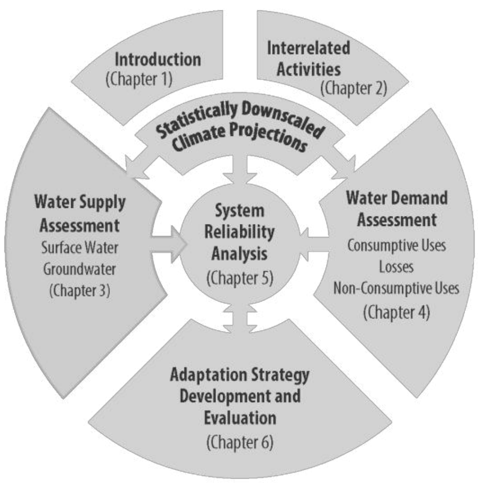



**Figure 3-1. Overall approach for Klamath River Basin Study, highlighting Chapter 3**

The water supply assessment consists of analyses of both surface and groundwater resources, including quantification of historical trends and projections for two future planning horizons, the 2030s (represented as the mean from 2020–2049) and 2070s (represented as the mean from 2060–2089). The water demand assessment (Chapter 4 of the Klamath River Basin Study) consists of analysis of agricultural, tribal/cultural, environmental, evaporative demands, and domestic, municipal, and industrial demands. Statistically downscaled

climate projections provide the basis for the assessments of projected water supply and demand. They are also used directly, along with supply and demand information, to evaluate the river system with respect to environmental demands such as water quality. Current and projected water supply and demand are brought together to evaluate how the river system has responded historically to changes in supply and demand, and may respond in the future as a result of climate change. Potential water supply/demand gaps are evaluated as part of a system reliability analysis. Performance measures are used to analyze system reliability; these are developed through an input process involving Klamath River Basin Study cost share partners, stakeholders, and tribes. The analysis of system risk and reliability is summarized in Chapter 5.

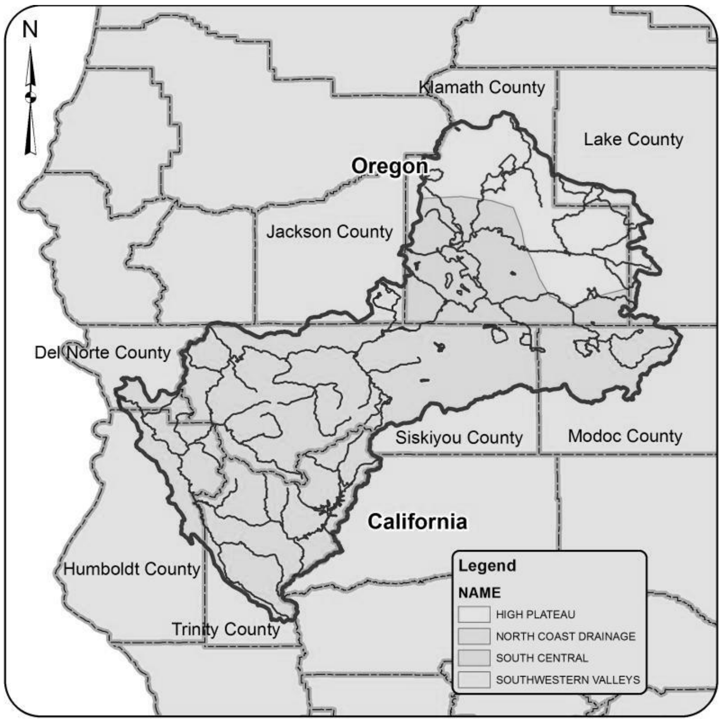
This chapter summarizes the findings of the current and future water supply assessment. The chapter begins with a general discussion of surface and groundwater resources in the watershed, followed by discussions of the technical approach for evaluation of historical water supply (surface and groundwater) and an assessment of historical water supply. The chapter then assesses projected water supply (surface and groundwater), including a detailed discussion of the approach for developing climate scenarios. The assessment of historical and projected surface water supply encompasses the entire Klamath River watershed, while the assessment of historical and projected groundwater supply is focused on three dominant groundwater basins in the watershed: the Upper Klamath Basin, Shasta Valley, and Scott Valley. The difference in approach is due to the extents of existing surface and groundwater modeling tools that may be applied in the study.

## 3.2 Description of Surface and Groundwater Supplies

This section briefly describes the general characteristics of surface and groundwater in the Klamath River Basin. These characteristics provide context for subsequent analysis of historical and projected water supply throughout the watershed. As previously mentioned, surface water supply is analyzed basin-wide, concentrated on three primary regions for analysis of groundwater supply: the Upper Klamath groundwater basin, the Scott Valley groundwater basin, and the Shasta Valley groundwater basin.

The Klamath River Basin is a complex watershed, due in part to its distinct climatic regions and distinct geologic zones which influence surface and groundwater interactions throughout the watershed. The Klamath River Basin spans four NOAA climate divisions, including High Plateau, North Coast Drainage, South Central, and Southwestern Valleys (Figure 3-2). Climate divisions are generally climatically distinct regions; however, they are also defined by political boundaries, as evidenced on Figure 3-2 where climate divisions are separated by the Oregon-California border and, in one case, by county boundaries (the boundary between Southwestern Valley and South Central).

The elevation ranges of Klamath River Basin climate divisions help to illustrate the complexity of the watershed. Basin-wide elevations range from sea level to about 13,600 feet. These two elevation extremes both fall within the North Coast Drainage climate division. The High Plateau ranges between 4,200 feet and 8,500 feet, while the South Central region ranges between 2,870 feet and 8,000 feet. Even the Southwestern Valley Climate Division, which covers only 15 percent of the watershed, ranges between 3,000 feet and 9,040 feet.



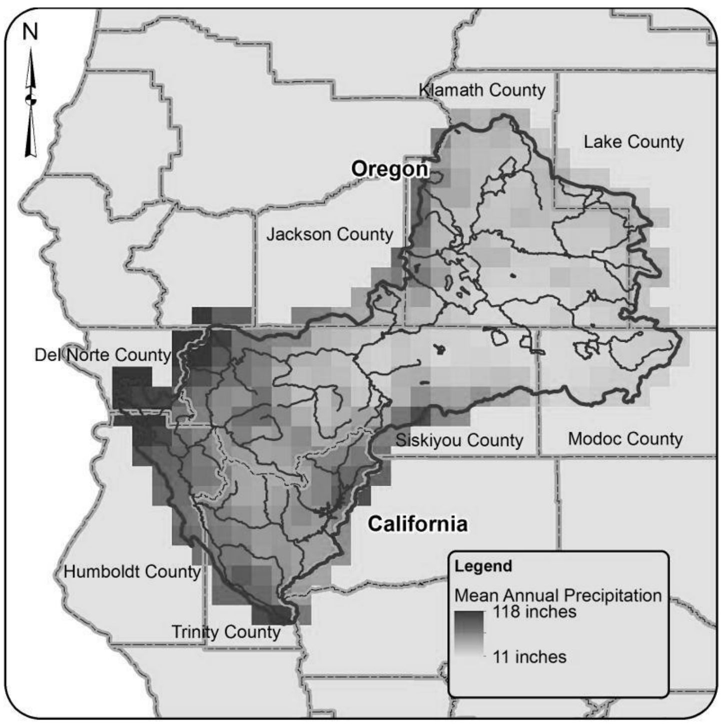

*Source: NOAA, http://www.esrl.noaa.gov/psd/data/usclimdivs/boundaries.html.*

**Figure 3-2. Map of climate divisions within the Klamath River Basin**

Mean annual precipitation and temperature were computed for the three dominant climate divisions within the watershed over calendar years 1950–1999, based on a widely used grid-based meteorological dataset developed by Maurer et al. (2002). This historical meteorological dataset is used as the basis for the historical and projected water supply assessments, as discussed later in this chapter.

Mean annual precipitation varies substantially across the three dominant climate divisions within the watershed (Figure 3-3), from about 24 inches per year in the

South Central to about 44 inches per year in the North Coast Drainage and about 26 inches in the High Plateau. The historical basin-wide mean annual precipitation over the same period is approximately 37 inches per year. Mean annual average temperature varies from almost 41 degrees Fahrenheit (F) in the High Plateau to 43 degrees F in the South Central and about 46 degrees F in the North Coast Drainage climate division, with a basin-wide average of 45 degrees F (computed over the same 1950–1999 period as for precipitation).




*Source: based on meteorological data from Maurier et al., 2002*

**Figure 3-3. Mean annual precipitation (inches/year) over the period 1950–1999**

The seasonality of precipitation and temperature in the Klamath River Basin is typical of coastal watersheds, where the winter season (defined as December through February) experiences the greatest precipitation, about 18 inches per year for this watershed historically (1950–1999), ranging from about 10 inches per year in the South Central to about 11 inches in the High Plateau and 22 inches in the North Coast Drainage. The summer season (defined as June through August) experiences relatively dry conditions, receiving about 2 inches per year for the same period with less than 12 percent of that experienced in the winter, and

ranging from slightly less precipitation in the North Coast Drainage to slightly more in the High Plateau.

Winter temperatures average about 31 degrees F over the historical period 1950–1999 across the basin and range from about 29 degrees F in the High Plateau and South Central to about 33 degrees F in the North Coast Drainage. Summer temperatures average about 60 degrees F basin-wide and range from about 58 degrees F in the High Plateau to about 60 degrees F in the South Central and about 61 degrees F in the North Coast Drainage. Note that diurnal fluctuations in temperature as well as temperatures at different elevations may vary substantially from these daily averages.

**Table 3-1. Summary of Klamath River Basin characteristics**

| | Basin Wide | North Coast Drainage | South Central | High Plateau |
|---|---|---|---|---|
| Mean annual precipitation | 37 inches | 44 inches | 24 inches | 26 inches |
| Mean winter precipitation | 18 inches | 22 inches | 10 inches | 11 inches |
| Mean summer precipitation | 2.1 inches | 1.9 inches | 2.1 inches | 2.4 inches |
| Mean annual daily average temperature | 45 degrees F | 46 degrees F | 43 degrees F | 41 degrees F |
| Mean winter daily average temperature | 31 degrees F | 33 degrees F | 29 degrees F | 29 degrees F |
| Mean summer daily average temperature | 60 degrees F | 61 degrees F | 60 degrees F | 58 degrees F |
| Runoff ratio | 0.46 | 0.52 | 0.27 | 0.24 |
| Elevation range | 0–13,600 feet | 0–13,600 feet | 2,870–8,000 feet | 4,200– 8,500 feet |

### 3.2.1 Surface Water

The Klamath River Basin may be considered a mixed rain and snow influenced watershed. March has historically had the greatest snowpack, averaging about 4.5 inches across the basin (statistics based on historical hydrologic model results are discussed below).

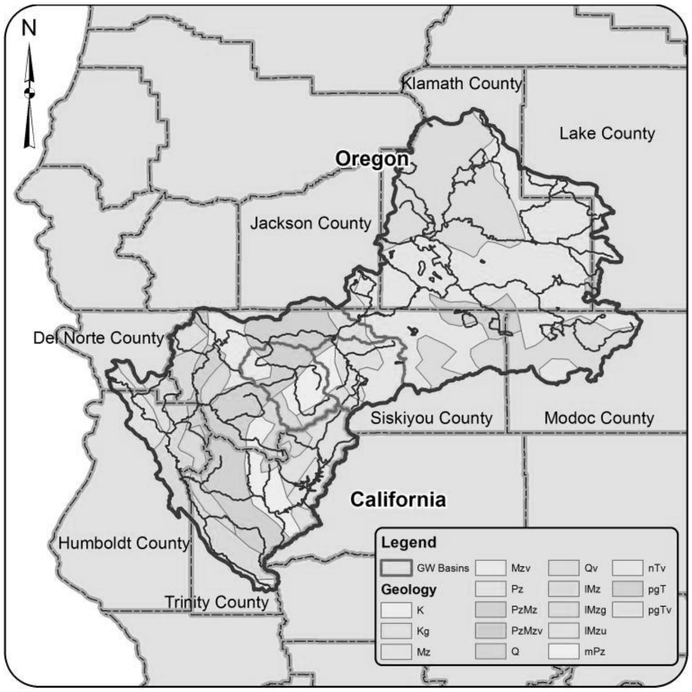
As previously mentioned, the relative magnitudes of key elements of the water balance in the Klamath River Basin vary due to its climatic diversity. Precipitation is one key element of the water balance described above. Other key elements include runoff and evapotranspiration. The ratio of mean annual runoff to mean annual precipitation is an indicator of how much precipitation results in streamflow as opposed to being lost through evapotranspiration or to groundwater recharge. On the whole, the basin has a historical runoff ratio of about 0.46, which translates to 46 percent or almost half of annual precipitation resulting in streamflow. This ratio varies substantially by climate division, from about 0.24 in the High Plateau climate division to about 0.27 in the South Central climate division and 0.52 in the North Coast climate division. In the High Plateau and South Central climate division areas evapotranspiration rates are higher, resulting in lower runoff ratios. In general, over snowmelt-dominated basins of the western

U.S., runoff ratios are typically close to 0.5. Little is known regarding how runoff ratios may change in a changing climate; however, future research may shed light on this question.

### 3.2.2 Groundwater

Groundwater systems are dynamic, with rates of recharge and discharge and hydraulic head varying in response to external stresses. Climate is one primary external influence on groundwater systems, along with human-caused stresses such as pumping, artificial recharge from canal leakage, and other sources. This section offers an overview of three primary groundwater basins to provide context for analysis of historical and projected future conditions in these areas and to provide greater understanding of how climate and other stressors may influence them.

The Klamath River Basin spans numerous geologic formations including volcanic, sedimentary, and granitic (Figure 3-4 and Table 3-2). Each formation, with its various overlying soil types, causes unique surface and groundwater interactions. Groundwater is an important water source for fish, wildlife, irrigators, and residents throughout the watershed, and in particular the Upper Klamath Basin and Scott and Shasta Valleys. For example, it provides cool, late summer streamflows to sustain fish at a critical time for spawning and rearing. In another example, some irrigators depend on groundwater supply to supplement surface water supplies during low water years where surface water supplies may not fully meet water needs, while many more irrigators depend solely on groundwater supplies. Increasing reliance on groundwater makes this an important component of the water supply assessment.




*Source: Generalized Geologic Map of the United States, http://pubs.usgs.gov/atlas/geologic/*

**Figure 3-4. Map of geologic units within the Klamath River Basin**

**Table 3-2. Descriptions of Klamath River Basin geologic types by ID as represented in Figure 3-4**

| ID | Geology | ID | Geology |
|---|---|---|---|
| nTv | Neogene volcanic rocks | lMzu | Lower Mesozoic ultramafic rocks |
| Qv | Quaternary volcanic rocks | mPz | Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks |
| Mz | Mesozoic sedimentary rocks | lMzg | Lower Mesozoic granitic rocks |
| pgTv | Paleogene volcanic rocks | mPz | Middle Paleozoic (Silurian, Devonian, and Mississippian) sedimentary rocks |
| pgT | Paleogene sedimentary rocks | Pz | Paleozoic sedimentary rocks |
| PzMzv | Paleozoic and Mesozoic volcanic rocks | lMzg | Lower Mesozoic granitic rocks |
| lMz | Lower Mesozoic (Triassic and Jurassic) sedimentary rocks | Kg | Cretaceous granitic rocks |
| PzMz | Paleozoic and Mesozoc sedimentary rocks | K | Cretaceous sedimentary rocks |
| Mzv | Mesozoic volcanic rocks | Q | Quaternary deposits |

As noted previously, the Klamath River Basin Study water supply assessment focuses on three primary groundwater basins including the Upper Klamath Basin, the Scott River Valley (Scott Valley), and the Shasta River Valley (Shasta Valley). The Upper Klamath Basin includes agricultural areas upstream of Upper Klamath Lake and areas in and surrounding Reclamation's Klamath Project, as well as Butte Valley and the Lost River drainage. Each of the three dominant groundwater basins is described below and highlighted in Figure 3-4.

#### *3.2.2.1 Upper Klamath Groundwater Basin*

The Upper Klamath groundwater basin spans about 8,000 square miles upstream of Iron Gate Dam on the Klamath River. Gannett et al. (2012) estimated approximately 500,000 acres of irrigated land for agriculture in 2011. Descriptions of the Upper Klamath groundwater basin primarily come from studies by Gannett et al. (2007) and Gannett et al. (2012).

The Klamath River Basin spans the Cascade Range geologic province (roughly corresponding with the Lower Klamath Basin) and Basin and Range geologic province (roughly corresponding with the Upper Klamath Basin). The Western Cascades sub-province of the Cascade Range constitutes part of the western boundary of the regional groundwater flow system and has very low permeability. The High Cascade sub-province of the Cascade Range consists mostly of volcanic vents and lava flows. There are two main areas in the Upper Klamath Basin with these Quaternary volcanic deposits: near Crater Lake (forming part of the northwest Upper Klamath Basin boundary), and from Mount Shasta east to Medicine Lake Volcano (forming part of the southern Upper Klamath Basin boundary).

Groundwater recharge from precipitation accounts for about 20 percent of the total precipitation in the Upper Klamath Basin. The exact percentage varies spatially and temporally (Gannett et al., 2007). The primary recharge areas in the upper Klamath Basin are the Cascade Range and uplands within and on the eastern margin of the basin. In the northeast part of the Upper Klamath Basin, basalt formations are an important source of recharge due to their high permeability. According to multiple references, at least 60 percent of the inflow into Upper Klamath Lake can be attributed to ground-water discharge in the Wood River sub-basin and springs in the lower Sprague River drainage and the Williamson River drainage below Kirk (Gannett et al., 2007).

Basin and Range Province deposits in the study area include a region from Clear Lake Reservoir eastward to the Upper Klamath Basin boundary. This region generally has low permeability. The region around the Tule Lake sub-basin and to the south consists of major water-bearing volcanic rock from the Late Miocene to Pliocene eras. Rock from these periods consists of volcanic vent deposits and flow rocks. These are generally located throughout the area east of Upper Klamath Lake and Lower Klamath Lake, underlying most of the valley-fill and basin-fill deposits in the study area. The lake deposits near the original lakebeds have much lower groundwater yield due to low permeability and a tendency to

have confining layers. About a mile below J.C. Boyle Dam, a large spring complex contributes significant flow to the Klamath River, on the order of 200 cubic feet per second.

The City of Klamath Falls, which is the primary population center in the Upper Klamath Basin at about 21,000 residents, is entirely supported by groundwater sources. Demand for groundwater has increased in recent decades in the Upper Klamath Basin as a replacement water source for both municipal and agricultural uses.

#### *3.2.2.2 Scott Valley Groundwater Basin*

The Scott River is a major tributary of the Klamath River. The Scott Valley sub-basin consists of 813 square miles, approximately 63 percent in private land and 37 percent in federally managed lands (Harter and Hines, 2008). It is fed by a number of tributaries, many of which become dry in the summer months. CDWR Bulletin 118 (2003), which describes California's primary groundwater basins, characterizes the Scott Valley Groundwater Basin as a narrow alluvial floodplain about 28 miles long and ½ mile to 4 miles wide. The basin boundary is generally defined as the contact between the valley alluvium and rocks from the surrounding mountains, dating from Pre-Silurian to Cretaceous. The CDWR Bulletin 118 groundwater basin within the Scott Valley defines the model domain for the assessment of groundwater supply for this region.

The largest water storage in the watershed occurs in the alluvial fill of the Scott Valley groundwater basin, which is recharged annually by the Scott River and tributary streams, and by infiltration of precipitation and snow melt. This flood plain aquifer area was calculated to represent more than half of the total groundwater stored in the Scott Valley (Mack, 1958). The recent alluvium ranges in thickness from less than one foot to greater than 400 feet in the center of the Scott Valley at its widest point. The thickness of the alluvium decreases both to the north and to the south (Harter and Hines, 2008).

The Scott Valley's largest municipalities, Etna and Fort Jones, use a combination of surface and groundwater sources. Most rural residences use wells, but a few are served by springs and surface diversions (Harter and Hines, 2008). Land use is dominated by agriculture and cattle-raising. Almost 90 percent of the agricultural area within Scott Valley is used for alfalfa and pasture (CDWR, 2000). CDWR (2003) estimates that groundwater use for agriculture and municipal/industrial demand is about 1,300 acre-feet (AF), based on the 1991 flow augmentation survey for Scott Valley (CDWR, 1991).

#### *3.2.2.3 Shasta Valley Groundwater Basin*

The Shasta River is near the size of the Scott Valley and encompasses almost 800 square miles. The agricultural area within the Shasta Valley is comprised primarily of pasture and alfalfa, which amounts to about 80 percent of the total agricultural area. Many sub-basins of the Shasta Valley have pasture/hay and cultivated crops, which together account for more than 10 percent of the land area.

CDWR Bulletin 118 describes the Shasta Valley as having Quaternary alluvium as the primary formation supporting groundwater. This formation appears continuous throughout the valley region. Mack (1960) also reported volcanic rock formations of the western Cascade Mountains and the ancestral Mount Shasta debris avalanche. The southeastern boundary of the watershed is formed by Mount Shasta, one of the few glacier peaks in California. Glacial melting on Mount Shasta and mountain precipitation are principal sources of groundwater recharge in the Shasta Valley. A portion of this recharge reaches the Shasta River through spring discharge in the vicinity of Big Springs (CDWR, 1991). The CDWR Bulletin 118 groundwater basin within the Shasta Valley defines the model domain for the assessment of groundwater supply for this region.

The hydrology of the Shasta River has been and continues to be affected by Dwinnell Dam (built in 1928 and raised in 1955), surface water diversions, and interconnected alluvial groundwater pumping. Domestic, municipal, and industrial water use information available for the Shasta Valley, which had a population of 18,225 based on the 2000 Census, primarily consists of urban water management plans for the cities of Yreka and Weed, California. Water supply for the City of Yreka, with a population of 7,765 according to the 2010 Census, is completely sourced from surface water. The water supply for Weed, with a 2010 population of 2,967, is comprised of springs and wells.

## 3.3 Historical Surface Water Availability

This section summarizes historical and current surface water availability in the Klamath River Basin. Specifically, it provides a brief discussion of previous studies, a discussion of data and models used, and an analysis of historical availability and trends. Although the literature synthesis (Appendix A of the Klamath River Basin Study Report) contains a detailed discussion of previous studies, this section touches on those related to historical water supply availability to provide context for the assessment of surface water supplies.

### 3.3.1 Previous Studies

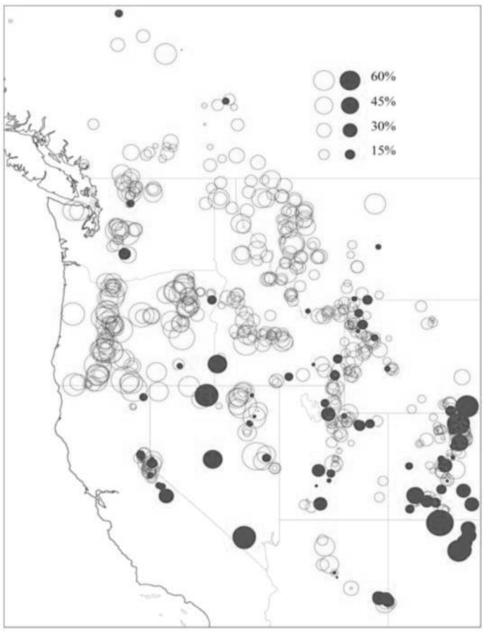
Numerous studies conducted over regions including northern California show increasing trends in historical temperatures, both annually and seasonally (Bonfils et al., 2007; Cayan et al., 2001; Dettinger and Cayan, 1995). Temperature increases over the 20th century have been estimated at 1.7 degrees F (1895–2011 over California by Moser et al., 2012) and 0.2–1.5 degrees F (difference between

1991–2007 and 1961–1990 over Shasta-Trinity National Forest by Furniss et al., 2012). Historical trends in precipitation have been inconsistent. Furniss et al. (2012) found no apparent increase in precipitation variability, but found an increase in winter, defined as January and February (0.1 to 7.9 inches) and growing season precipitation (0.1 to 2.1 inches). Research has shown small increasing trends in the frequency of historical extreme events over the mid-Pacific region (Kunkel, 2003; Madsen and Figdor, 2007; Gutowski et al., 2008).

Historical trends in snowpack and runoff over Northern California include declines in spring snowpack and earlier snowmelt runoff (Knowles et al., 2007; Regonda et al., 2005; Peterson et al., 2008; Stewart, 2009; Furniss et al., 2012; Reclamation, 2011c). However, glaciers on Mount Shasta are among the few in the world that are increasing in size (Furniss et al., 2012). Note that any trends in climate and water balance (i.e., snowpack and runoff) are dependent on the time period of analysis and are a direct result of the combined influences of natural climate variability and climate change (Reclamation, 2011k).

In the Upper Klamath River Basin, dry season (April to September) and summer streamflow (July to September) declined 16 percent and 38 percent, respectively during the period between 1961 and 2009 (Mayer and Naman, 2011). This decline is closely associated with decline in April 1 snowpack, which decreased approximately 40 percent during the same study period for snowcourse sites located below 1820 meters (5,970 feet) in elevation.

In response to temperature increases in the Pacific Northwest (Cayan et al., 2001; Regonda et al., 2005), snowpack in western North America has declined over the past 50 years (Mote et al., 2008). Figure 3-5 illustrates declines in April 1 snow water equivalent (SWE) at 594 locations in the western U.S. and Canada between 1950 and 2000. Mote et al. (2008) noted that the Pacific Northwest (generally including Washington, Oregon, and Idaho) has experienced the largest decline in snowpack in the western U.S. Although many regions have experienced decreasing trends, some regions have experienced increasing trends in April 1 SWE, namely in parts of the southwestern U.S.




*Source: Mote et al., 2008*
Note: Negative trends are shown by open red circles, positive trends by solid blue circles.

**Figure 3-5. Relative trends in April 1 SWE at 594 locations in the western U.S. and Canada, 1950–2000**

Attribution studies have aimed to distinguish historical trends due to climate change versus trends due to natural climate variability (Bonfils et al., 2007 and Cayan et al., 2001 for the western United States; Gershunov et al., 2009 for California and Nevada). Bonfils et al. (2008) found that increases in daily minimum and maximum temperatures over 1950–1999 cannot be fully explained by natural climate variability. Pierce et al. (2008) found that climate change may be the cause of about half of reductions in the fraction of annual precipitation falling as snow observed in the western United States from 1950 to 1999. The strongest changes in winter runoff, and in the fraction of precipitation accumulated as snow, have occurred at medium elevations (750–2,500 meters or 2,460–8,200 feet and 500–3,000 meters or 1,640–9,840 feet, respectively) close to freezing level. These are not likely to be associated with natural variability (Hidalgo et al., 2009). Barnett et al. (2008) found that, over the western United States, up to 60 percent of the climate-related trends in streamflow are human induced. These as well as other attribution studies of streamflow timing (Hidalgo et al., 2009 and Das et al., 2009) and snow/rain days (Das et al., 2009) show that statistical significance of the anthropogenic signal is greatest at the scale of the

western U.S. and weak or absent at the watershed scale, except in the Pacific Northwest (Hidalgo et al., 2009). However, attribution of any apparent trends in precipitation to climate change remains difficult (Hoerling et al., 2010).

### 3.3.2 Approach

The general approach for assessing historical surface water supply in the Klamath River Basin is to evaluate how historical climate has influenced the quantity, timing, and form of precipitation falling on the landscape. Assessment of historical water supply involves (1) evaluating trends in historical climate using a widely used spatially distributed meteorological dataset; (2) utilizing a hydrologic model to simulate the partitioning of precipitation into snow storage, evapotranspiration, runoff, and recharge to groundwater based on meteorological inputs and landscape characteristics; and (3) evaluating trends in historical water balance parameters based on hydrologic model simulations. This overall approach is illustrated by Figure 3-6.

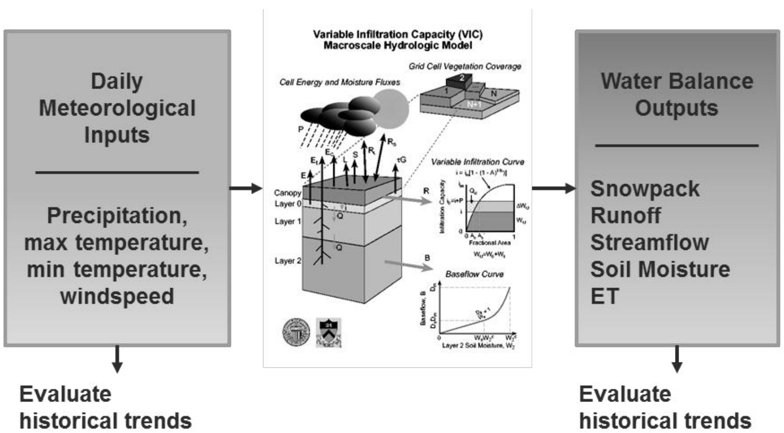



**Figure 3-6. Summary of approach for assessment of historical surface water availability**

For the Klamath River Basin Study, current and future water supply assessments rely on the variable infiltration capacity (VIC) model for simulation of surface water hydrology. The VIC model (Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) is a grid-based hydrologic model that solves the water balance at a spatial scale of 1/8$^{th}$ degree, or approximately 10 kilometers on a side. Details regarding the VIC model and the configuration used in the Klamath River Basin water supply assessment are provided in Appendix B, Supplemental Information for Assessment of Water Supply; however, details relevant to this study are provided below.

The VIC model requires gridded daily precipitation, maximum and minimum temperatures, and wind speed magnitude (at a minimum) as input to simulate water balance variables. The Klamath River Basin Study utilizes historical gridded observations developed by Maurer et al. (2002) for the period from January 1949 to July 2000. Additional model forcings that drive the water balance, such as solar (short-wave) and long-wave radiation, relative humidity, vapor pressure, and vapor pressure deficit, are calculated within the model.

The VIC model outputs may be defined by the user, but typically include grid cell water balance terms such as evapotranspiration, baseflow, or runoff. Gridded surface runoff and baseflow are hydraulically routed to produce streamflow at a select group of locations, using the model presented by Lohmann et al. (1996). Routed streamflow using this approach represents natural streamflow – that is, streamflow that would occur in the absence of water management (i.e., diversions, return flows, and storage). For climate change impact studies, VIC is commonly run in water balance mode due to its higher computational efficiency compared to the alternative energy balance mode, which facilitates numerous projected climate simulations.

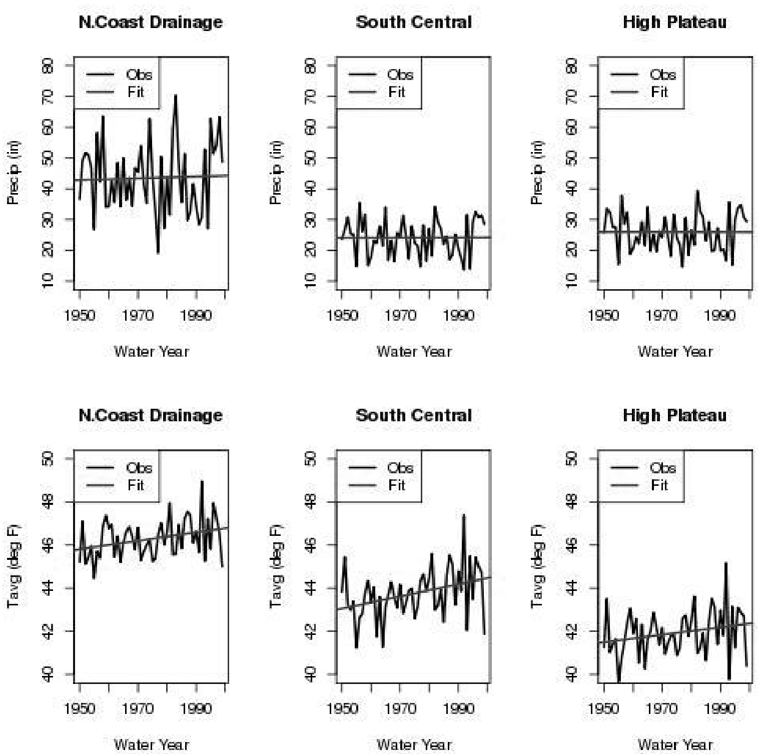
### 3.3.3 Present Availability and Historical Trends

This section summarizes present climate and surface water availability as well as historical trends. Historical simulated trends in climate and water balance variables are based on data used in the Klamath River Basin water supply assessment. The trends presented for climate (precipitation and temperature) likely have less uncertainty than those based on water balance parameters, primarily because climate trends were computed based on interpolated observations whereas water balance trends were computed based on hydrologic model output. Where appropriate, results are compared with findings from previous studies.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. For example, this dataset was used to develop climate and hydrologic projections developed and supported by Reclamation as part of its West-Wide Climate Risk Assessment (Reclamation, 2011d) and data portal (Archive Collaborators, 2000). The dataset has been extended beyond the original July 2000 date to December 2010 (Maurer et al., 2010). However, we utilized the original dataset as the basis for evaluating historical hydrology in the region to maintain consistency with previous efforts.

Historical trends in April 1 SWE, total annual runoff, total annual evapotranspiration, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model described briefly in the previous section. Because summer months typically receive low precipitation in the Klamath River Basin (see Table 3-1), soil moisture is an important water source

for natural vegetation and perhaps some dryland agriculture. Hence, the Klamath River Basin Study Water Supply Assessment reports trends in June 1 soil moisture, which was found to be the month with maximum soil moisture in the greater watershed. Trends were computed over the entire Klamath River Basin, as well as over the three dominant climate divisions within the basin: North Coast Drainage, South Central, and High Plateau. The fourth climate division within the watershed, Southwestern Valleys, covers only a small portion of the watershed (spanning just five spatially distributed VIC model grid cells). Therefore, data for this region is not summarized.




Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

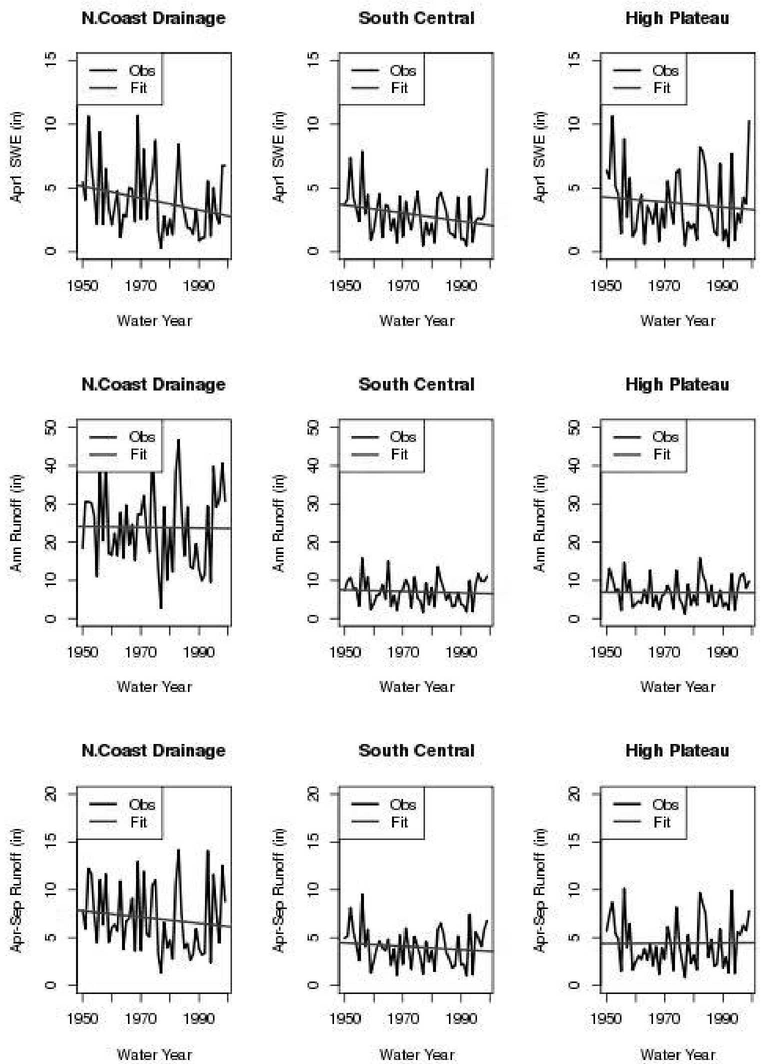
**Figure 3-7. Trends in mean annual water balance parameters (precipitation and temperature) over 1950–1999 water years**

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50-year period), small but increasing trends over the portions of the basin within the North Coast Drainage and South Central Climate Division (about 1.3 inches [+3 percent] and +0.1 inches [+0.5 percent] over the 50-year period, respectively), and a small decreasing trend over the portion of the basin within the High Plateau Climate Division (-0.03 inches [-0.1 percent]). None of these historical trends is statistically significant at the 95th percentile level (see Figure 3-7 and Table 3-3 for a summary of trends). The combination of both increasing and decreasing historical trends in precipitation over parts of the watershed is consistent with previous findings (Hoerling et al., 2010) showing a lack of clear historical change signal for annual precipitation.

All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999 (Figure 3-7 and Table 3-3). The trends in those portions of the basin within the North Coast and South Central climate divisions, as well as in the basin as a whole, are statistically significant at the 95th percentile level. Historical trends in mean annual temperature (+1 degree F basin-wide and +0.8 to +1.4 degrees F, depending on the climate division) are consistent with previous findings indicating positive change in temperature (Moser et al., 2012; Furniss et al., 2012).

Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide as well as for each of those portions of the basin within the North Coast, South Central, and High Plateau climate divisions (see Figure 3-8 and Table 3-3). Historical trends basin-wide indicate about a 41 percent decrease in April 1 SWE, with a range of about 22 percent to 45 percent over the portions of the basin within the three dominant climate divisions. The range of historical decreases in SWE computed by this study closely corresponds with the reported decrease in Upper Klamath Basin April 1 SWE by Mayer and Naman (2011) of 40 percent over the period 1961–2009, using snow course measurements below about 6,000 feet. Although the computed declines in April 1 SWE may be considered substantial, none are statistically significant at the 95th percentile level.

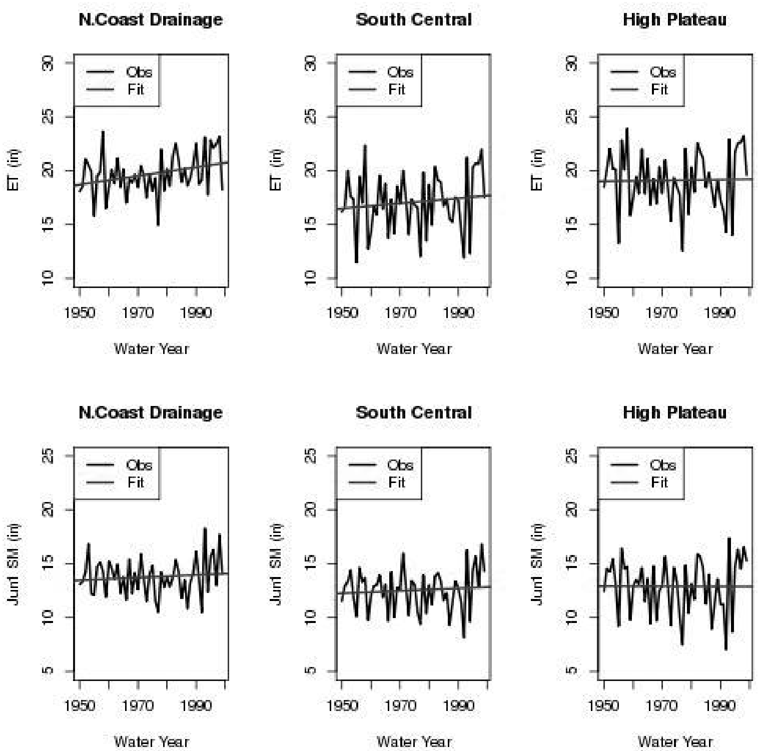
Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent, with a range of 4 to 22 percent depending on the climate division (see Figure 3-8 and Table 3-3). Mayer and Naman (2011) reported larger declines in streamflow over the 1961–2009 period (16 to 38 percent), albeit over spring and summer months only. None of the computed trends in runoff (regional or basin-wide) are statistically significant at the 95th percentile level.




Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

**Figure 3-8. Trends in mean annual water balance parameters (April 1 SWE, annual runoff, and irrigation season runoff) over 1950–1999 water years**

Evapotranspiration (ET), as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide (see Figure 3-9 and Table 3-3). Portions of the basin within the three dominant climate divisions indicate a range of increase from about 1 percent in the High Plateau region to 11 percent in the North Coast Drainage region. The increase in ET is statistically significant at the 95th percentile level for the North Coast Drainage climate division only.




Note: Trends are computed based on portions of the Klamath River Basin that fall within three dominant climate divisions: North Coast Drainage (left), South Central (middle), and High Plateau (right).

**Figure 3-9. Trends in mean annual water balance parameters (annual evapotranspiration and June 1 soil moisture) over 1950–1999 water years**

Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole, yet the trends by climate division range from a decrease of about 0.3 percent in the High Plateau region to an increase of 5 percent in the South Central region and an increase of 4 percent in

the North Coast Drainage region (Figure 3-9 and Table 3-3). These trends are not statistically significant at the 95th percentile level.

**Table 3-3. Mean change over 1950–1999 period (water years) by climate division within the Klamath River Basin and basin wide**

| | Basinwide | | N Coast Drainage | | South Central | | High Plateau | |
|---|---|---|---|---|---|---|---|---|
| **Precip** | +0.8in | +2% | +1.3in | +3% | -0.1in | +0.5% | -0.03 in | -0.1% |
| **Tavg** | **+1°F** | **--** | **+1.0°F** | **--** | **+1.4°F** | **--** | **+0.8°F** | -- |
| **April 1 SWE** | -2.0in | -41% | -2.3in | -45% | -1.6in | -42% | -1.0 in | -22% |
| **Annual Runoff** | -0.5in | -7% | -0.5in | -6% | -0.6in | -22% | -0.1 in | -4% |
| **Apr-Sep Runoff** | -1.2in | -18% | -1.6in | -20% | -0.9in | -19% | +0.1in | +2% |
| **Annual ET** | +1.5in | +8% | **+2.0in** | **+11%** | +1.2in | +7% | +0.2 in | +1% |
| **June 1 Soil Moisture** | 0.4in | +3% | +0.6in | +4% | +0.6in | +5% | -0.03 in | -0.3% |

Note: Numbers in bold indicate statistical significance of trends at the 95th percentile level.
Precip =mean annual precipitation/ Tavg = mean daily average temperature; SWE = snow water equivalent; ET = evapotranspiration

As previously mentioned, computed trends are highly dependent on the time period over which they are calculated. The primary reason for the dependence on duration is that, coincident with the low frequency trends resulting from human-induced climate change, there are various patterns of natural climate variability. Temporal patterns of climate variability in the Northwest are strongly influenced by variations over the Pacific Ocean, chiefly El Niño/Southern Oscillation (ENSO). ENSO involves linked variations in the tropical Pacific Ocean and overlying atmosphere. During the El Niño phase of ENSO the wintertime jet stream tends to split, with warmer air flowing into the Northwest and Alaska and a southern branch of the jet stream directing unusually frequent and heavy storms toward southern California. During the El Niño winter and spring, Oregon's climate is slightly more likely than usual to be warm and dry. The Pacific Decadal Oscillation (PDO) is another pattern of climate variability that acts similarly to ENSO, but typically over longer time frames (on the order of multiple decades). Depending on the time period chosen for trend analysis, patterns of natural climate variability may mask or

### Historical Surface Water Availability

Of historical precipitation, temperature, snowpack, runoff, evapotranspiration, and soil moisture, the only statistically significant trends at 95th percentile level are:

Temperature (all regions) and evapotranspiration (North Coast Climate Division).

amplify the apparent trends due to human-induced climate change. Choosing longer time periods over which to compute historical trends can help to reduce the relative influence of natural climate patterns on the computed trends.

## 3.4 Historical Groundwater Availability

For analysis of groundwater impacts of climate change, outputs from surface water hydrology simulations, informed by climate projections, may be used as inputs to groundwater models. For the Klamath River Basin Study, groundwater hydrology is simulated using the USGS MODFLOW, or moderate finite-difference flow model, over the Upper Klamath Basin (upstream of Iron Gate Dam), developed through studies by Gannett et al. (2007, 2012). This model simulates evapotranspiration, groundwater head, and discharge to streams, among other things. Groundwater hydrology is also simulated in the Scott and Shasta Valleys using a multiple regression-based tool. This groundwater simulation tool performs an overall water balance to simulate relative groundwater levels. This modeling tool may be used to evaluate projected changes in the overall water balance of these river systems, as well as to evaluate the effects of projected changes in streamflow on the groundwater system.

### 3.4.1 Previous Studies

Groundwater modeling studies have been previously conducted for parts of the Klamath River Basin including the Upper Klamath Basin (Gannett et al., 2007, 2012) and the Scott River Valley (S.S. Papadopulos & Associates, Inc., 2012). Additional groundwater modeling efforts are currently underway, including research studies in the Scott and Shasta Valleys by faculty and graduate students at the University of California at Davis (Harter and Hynes, 2008). These studies are further described below.

#### *3.4.1.1 Upper Klamath Basin*

Gannett et al. (2007, updated in 2010) completed a groundwater investigation of the Upper Klamath Basin, upstream of Iron Gate Dam, to improve understanding of the groundwater dynamics in the region. The investigation was based on collected data, monitoring, and analysis. Since 2001 the basin has experienced increased groundwater pumping, particularly within and near Reclamation's Klamath Project, in response to various biological opinions and court orders. A water bank program administered by Reclamation, as well as subsequent Klamath Water and Power Agency Water Use Management Plans, have purchased varying quantities of groundwater to supplement surface water in 8 of the past 11 years (2003 through 2013). The water bank provided incentives for irrigators to increase groundwater pumping during years of low surface water availability as a pathway for retaining greater instream flows.

In a subsequent study by Gannet et al. (2012), in collaboration with the OWRD and Reclamation, a MODFLOW finite-difference groundwater model was developed to represent the system and to improve understanding of the long term

effects of the above-described water banking program. In this investigation, the authors sought to identify the optimal strategy for meeting user needs while not exceeding defined impact constraints. This study found that some supplemental groundwater pumping could occur while not exceeding defined constraints, and that groundwater levels should recover from the observed declines if pumping was reduced to pre-2001 rates.

#### *3.4.1.2 Scott Valley*

A groundwater study for the Scott Valley (tributary region to the Klamath River, see Figure 3-13) was completed by S.S. Papadopulos & Associates, Inc. in 2012 for the Karuk Tribe. The study examined the impacts of groundwater pumping on the aquifer and on the Scott River by evaluating groundwater levels under three scenarios including recent use conditions, an alternative water use condition representing partial build-out of the existing groundwater capacity, and partial build-out with gradual increases in pumping levels.

Results from the study indicated that long-term declines in groundwater levels were minimal in winter and greater in late summer, corresponding with seasonal groundwater pumping. The declines can, and have, impacted streamflows. The model was used to develop a relationship between groundwater levels and stream depletions, showing that increases in groundwater pumping result in reductions in streamflow mostly within the first year or two (S.S. Papadopulos & Associates, Inc., 2012).

Researchers at the University of California, Davis completed the Scott Valley Community Groundwater Study Plan (Harter and Hynes, 2008, hereafter referred to as the UC Davis Groundwater Study Plan), which discusses the motivation for the approach of their ongoing groundwater modeling study for the Scott Valley. The study is being conducted in cooperation with Siskiyou County and Scott Valley stakeholders as a result of recommendations made in the TMDL Action Plan (State of California, 2005) and the Scott River Watershed Council Strategic Action Plan (Scott River Watershed Council, 2005). The State of California has determined that the water quality standards for the Scott River are exceeded due to excessive sediment and elevated water temperature. Studies on which the TMDL Action Plan is based state that groundwater inflows are a primary driver of stream temperatures in the Scott Valley, along with human-caused changes in riparian shading.

The UC Davis Groundwater Study Plan identifies a number of statements, hypotheses, and research questions that will be addressed during the study. A couple of noteworthy statements include: (1) there is a statistically significant correlation between SWE, total annual precipitation, and average Scott Valley groundwater table elevation in subsequent months/years, and (2) the magnitude and dynamics of seasonal and intra-annual groundwater level fluctuations have significantly changed since 1950.

The S.S. Papadopulos & Associates (2012) modeling study and the ongoing UC Davis groundwater study rely on a survey of geology and groundwater features of the Scott Valley conducted by the USGS in 1958 (Mack, 1958). The report describes in detail the geologic features in the basin and points out some interesting features of the groundwater system. Most of the wells in the area are shallow dug wells, averaging about 25 feet. Recharge to groundwater comes in the form of rainfall, seepage from tributary streams, and irrigation. Losses from groundwater come mainly in the form of evapotranspiration and hyporheic flow into the Scott River. Mack estimated the storage capacity in the flood-plain sediments to be about 220,000 acre-feet. As part of the Mack (1958) study, a number of groundwater level measurements were made either from existing or installed monitoring wells. A number of these wells continued to be used as monitoring wells. These data serve as a primary data source for subsequent Scott Valley groundwater modeling studies, including the current study presented in this chapter.

### 3.4.2 Approach – Upper Klamath Basin

Groundwater in the Upper Klamath Basin is being simulated using the USGS MODFLOW finite-difference model developed by Gannett et al. (2012). Details of the model configuration may be found in the mentioned study; however, a general discussion is included here. Emphasis in this discussion is placed on two elements of the model with direct linkages to the surface water hydrologic model developed over the region (VIC). The approach discussed below helps to provide context for the approach of evaluating the impacts of projected climate.

The MODFLOW model developed for the Upper Klamath Basin has 100,070 active cells and a historical simulation period of water years 1970 through 2004 (October 1969–September 2004). For the purposes of this study, and to maintain consistency with datasets used to evaluate surface water supply, the historical period was modified to water years 1970 to 1999. The model has quarterly stress periods (every 3 months) and each stress period is divided into five equal timesteps. Model input data are developed on a quarterly basis (i.e., disaggregation to individual timesteps occurs internally within the model).

The MODFLOW model utilizes a number of packages that help to improve its representation of physical processes. The packages implemented in this configuration include the recharge package, well package, stream package, general head boundary package, evapotranspiration package, drain package, and reservoir package, in addition to the basic package. There are two primary linkages with surface water inputs, such as outputs from the VIC surface water hydrologic model. First, VIC model precipitation inputs are used to develop seasonal relationships between precipitation and recharge, which are later used to develop scenarios of future recharge based on projected precipitation. Second, VIC simulated potential evapotranspiration (PET) and actual ET are used to compute the upper threshold for ET used by the MODFLOW model (computed as the difference between PET and actual ET). The modeling study conducted by

Gannett et al. (2012) relied on surface water inputs from the USGS Precipitation Runoff Modeling System (PRMS), developed over the same region.

Assessment of historical groundwater levels in the Upper Klamath Basin primarily comes from the modeling efforts by Gannett et al. (2012). However, as part of the assessment of groundwater supplies, the MODFLOW model was rerun over the modified historical period and is the baseline for comparison of projected groundwater levels.

### 3.4.3 Present Availability and Historical Trends – Upper Klamath Basin

Present availability and historical trends in groundwater elevation and recharge are discussed in the context of previously completed work by Gannet et al. (2012). The historical MODFLOW simulation described by Gannett et al. (2012) was used as the historical baseline for the assessment of groundwater in the Upper Klamath Basin for this water supply assessment.

Historical availability of groundwater is presented in this section with respect to recharge and groundwater elevations. Historical recharge to the groundwater system was developed by Gannett et al. (2012) using summed subsurface flow (interflow) and groundwater flow terms from the PRMS model. Subsurface (interflow) generated by PRMS represents shallow rapid subsurface flow, which is not well simulated by MODFLOW. Therefore, adjustment factors were applied to the summed recharge values to more accurately simulate recharge in the basin. The resulting historical recharge used as input to the MODFLOW model is illustrated by Figure 3-10.

The highest recharge, according to Figure 3-10, is along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains. The lowest recharge amounts are in the central and southern parts of the basin. It should be noted that amount of recharge does not necessarily correspond to areas with highest ground permeability. Discussions from Section "Upper Klamath Groundwater Basin", addressing groundwater characteristics of the basin, indicate that the western part of the basin is generally characterized by low permeability, while parts of the central basin are characterized as having high permeability and high groundwater yield. Greater recharge occurs along the western boundary primarily due to the fact that there is more water available for recharge, compared with the central portion of the basin.

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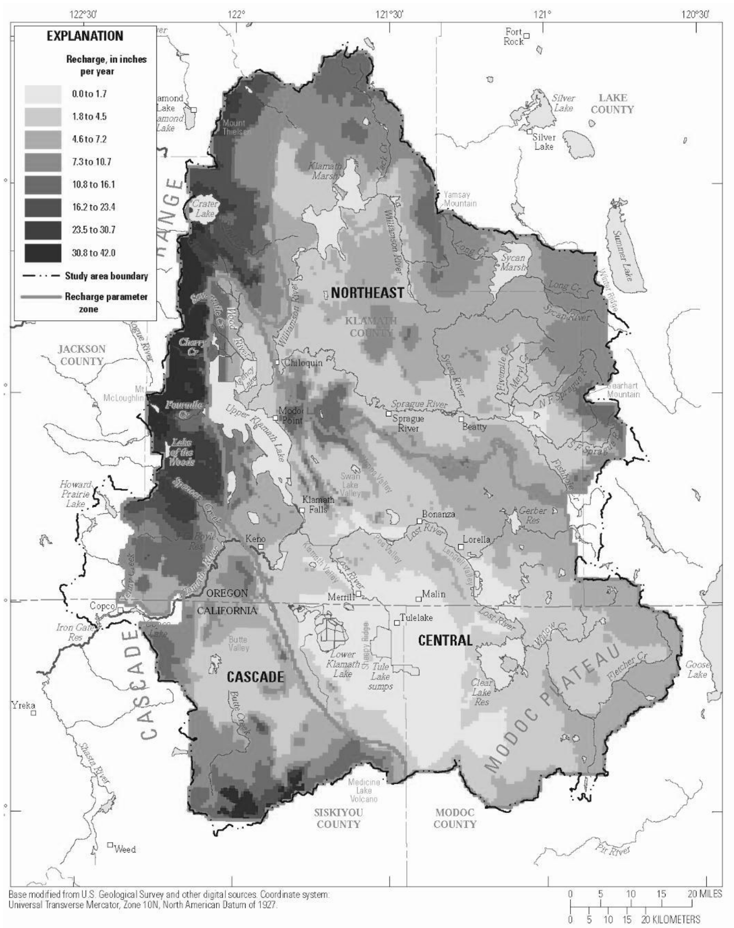


**Figure 7.** Estimated mean annual groundwater recharge from precipitation in the upper Klamath Basin, Oregon and California, 1970–2004, in inches, and recharge parameter zones.

*Source: Figure 7 from Gannet et al., 2012*

Note: Recharge Zone 1 (Cascade) lies along the western boundary of the basin. Recharge Zone 2 (Northeast) covers the northeastern part of the basin. Recharge Zone 3 (Central) covers the central and southeastern part of the basin.

**Figure 3-10. Summary of mean annual recharge over the Upper Klamath River Basin**

Gannett et al. (2012) also summarizes historical simulated groundwater elevations, compared with observations, for a number of sites throughout the Upper Klamath Basin model domain. We provide a sample of figures for two sites, including the Wood River sub-basin, located upstream of Upper Klamath

Lake (Figure 3-11) and the Lower Klamath Lake sub-basin, located in the southcentral portion of the model domain (Figure 3-12).

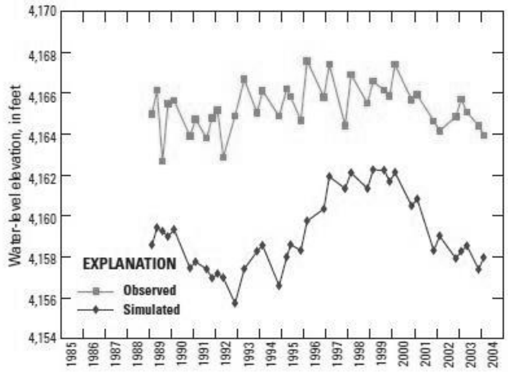



**Figure 18.** Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

*Source: Figure 18 from Gannett et al., 2012*

**Figure 3-11. Observed and simulated water-level elevations in the Wood River sub-basin**

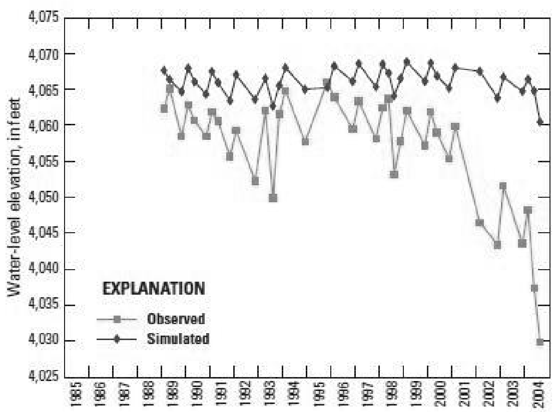



**Figure 36.** Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

*Source: Figure 36 from Gannett et al., 2012*

**Figure 3-12. Observed and simulated water-level elevations in the Lower Klamath Lake sub-basin**

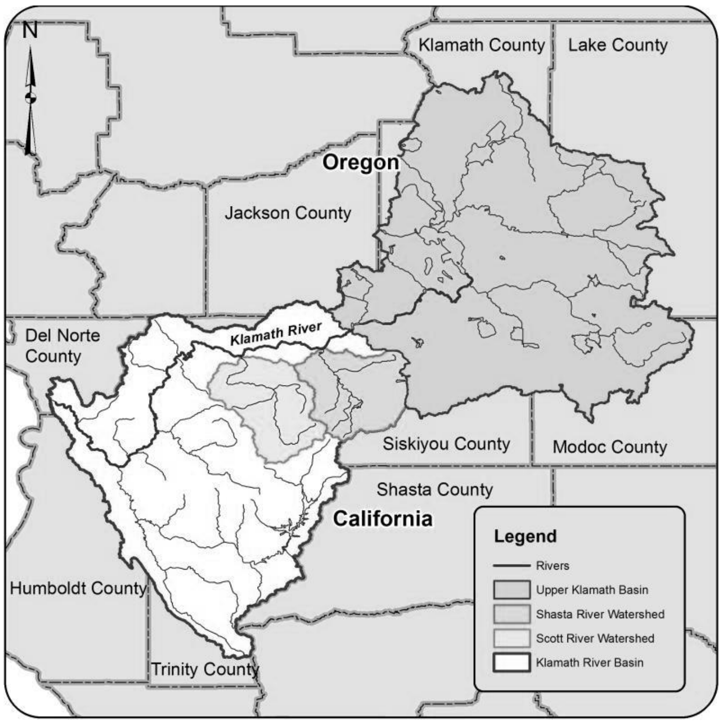
Results for these two sites are representative of the types of calibration results for the MODFLOW model. In general, the model captures the low frequency variability in groundwater levels over the period from the late 1980s through 2004. The model is also able to capture much of the year-to-year variability in groundwater levels. The difference between simulated and observed groundwater elevations can vary from on the order of 5 feet to 30 feet, depending on the site and year. Gannett et al. (2012) suggest the larger differences (seen in parts of the Wood River sub-basin as shown on Figure 3-11, for example) may be due to the coarse vertical discretization of the model, relative to the gradients of groundwater flow. Also for the Lower Klamath sub-basin site (Figure 3-12), the model is not able to capture the decline in observed groundwater elevation that occurs after about 2000 (corresponding with drought and increases in pumping). Differences between observed and simulated groundwater elevations may be attributed, at least in part, to lack of accurate information on rates and locations of pumping in some parts of this sub-basin (Gannett et al., 2012).

**Historical Groundwater Availability – Upper Klamath Basin**

The highest recharge to groundwater occurs along the western boundary of the Upper Klamath Basin on the eastern slopes of the Cascade Mountains, while the lowest recharge amounts are in the central and southern parts of the basin.

### 3.4.4 Approach – Scott and Shasta Valleys

The groundwater portion of the Klamath River Basin Study water supply assessment consists of analysis for three main regions within the Klamath River Basin: the Upper Klamath Basin, the Scott Valley, and the Shasta Valley (see Figure 3-13). These regions represent the majority of groundwater use in the Klamath River Basin, as inferred from defined groundwater regions from California's Groundwater Bulletin 118 (CDWR, 2003). To the extent possible, these analyses rely on existing modeling tools and data.




*Sources: Principal Aquifers, http://www.nationalatlas.gov/mld/aquifrp.html; Scott and Shasta Valley Well Data, http://www.water.ca.gov/waterdatalibrary/groundwater/index.cfm.*

**Figure 3-13. Map of modeled groundwater basins within the Klamath River Basin**

Existing groundwater modeling tools for the Scott and Shasta Valleys were explored in the preparation of this water supply assessment. No existing groundwater modeling tools were identified for the Shasta Valley, although there are ongoing studies at the University of California at Davis related to groundwater dynamics of the Shasta Valley.[3] There is also an existing draft groundwater data needs assessment developed by CDWR which has not been finalized (CDWR, 2011). The existing groundwater model for the Scott Valley, developed by S.S. Papadopulos & Associates, Inc. (2012) for the Karuk Tribe, was explored for possible use in the Klamath River Basin Study. However, use of this modeling tool was deemed infeasible due to the reasons outlined below:

[3] http://hsgg.ucdavis.edu/research/student-abstracts/

1. The modeling tool was not readily available for use by Reclamation. In other words, additional funding would have been required to either contract with S.S. Papadopulos & Associates, Inc. to participate in the study or fund them to package the model for use by Reclamation staff.
2. The model was designed with a relatively narrow focus on the impact of groundwater pumping on streamflows.
3. Confidence in the results from a sophisticated MODFLOW finite-difference groundwater model for the Scott Valley, where input data are limited, was not high enough to justify the cost of its implementation in the study.
4. The spatial resolution of the surface water hydrologic model that provides surface water inputs to the groundwater model is coarse in comparison with the size of the Scott River Basin, which also limits confidence in the utility of applying a sophisticated MODFLOW model in the basin.

Conceptual regression-based groundwater screening tools were developed for both the Scott and Shasta Valleys based on the approach taken by Reclamation (2013) in the Santa Ana Watershed Basin Study. The added advantage of developing these tools is consistency in the approach for the two neighboring watersheds. This section briefly describes the groundwater screening tool as it was applied in this Klamath River Basin Study. Details regarding data used as input to the Scott and Shasta Valley tools are described in Appendix B, Supplemental Information for Assessment of Water Supply.

The regression-based groundwater model relies on historical inflows and outflows from the groundwater system, estimated from available data, including spatially distributed recharge from precipitation, focused recharge from stream and canal seepage losses or deep percolation of irrigation water, groundwater abstraction by pumping, and other inflows and outflows. The model is calibrated and verified with respect to available observations. The model may then be applied using projected future conditions, as well as applied management alternatives, to evaluate the effects of climate change and adaptation strategies on groundwater resources.

The groundwater screening tool estimates fluctuations in basin-scale groundwater levels in response to natural and anthropogenic drivers, including climate and hydrologic conditions, agricultural land use, municipal water demand, and trans-basin water imports, if applicable. The tool allows users to quickly estimate basin-scale groundwater conditions under a broad range of future scenarios and provides insight into the primary factors driving basin-scale groundwater fluctuations.

This screening tool is based on a conceptual model which considers fluctuations in basin-average groundwater elevations as a function of basin-scale drivers.

These drivers are illustrated in Figure 3-14 and may be categorized by the following: water availability (precipitation, local streamflow, and trans-basin imports), water demand (municipal and industrial demand, agricultural land use, and evaporative demand), and an optional exogenous input that represents groundwater management objectives that affect basin-scale groundwater levels. As a result, use of the groundwater screening tool does not require detailed information regarding local hydrologic, geologic, climatic, and anthropogenic factors that may affect local groundwater fluctuations. However, it should be noted that as a result of this basin-scale approach, the groundwater screening tool is primarily applicable at the scale of individual groundwater basins or sub-basins, where the effects of local-scale conditions are largely averaged out and where subsurface inflows and outflows from surrounding areas are negligible.

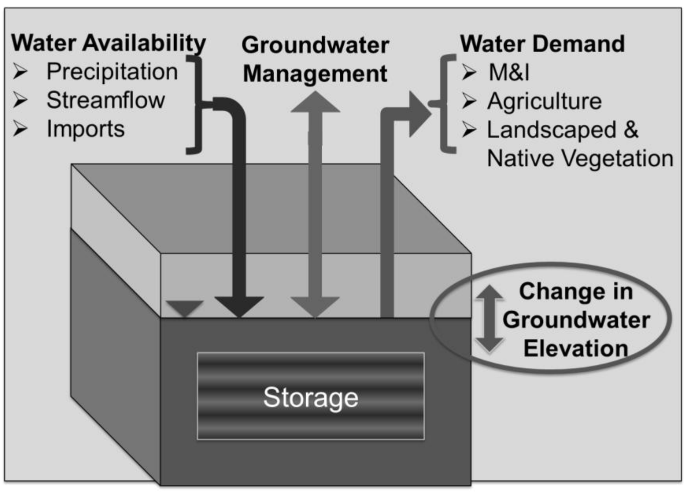
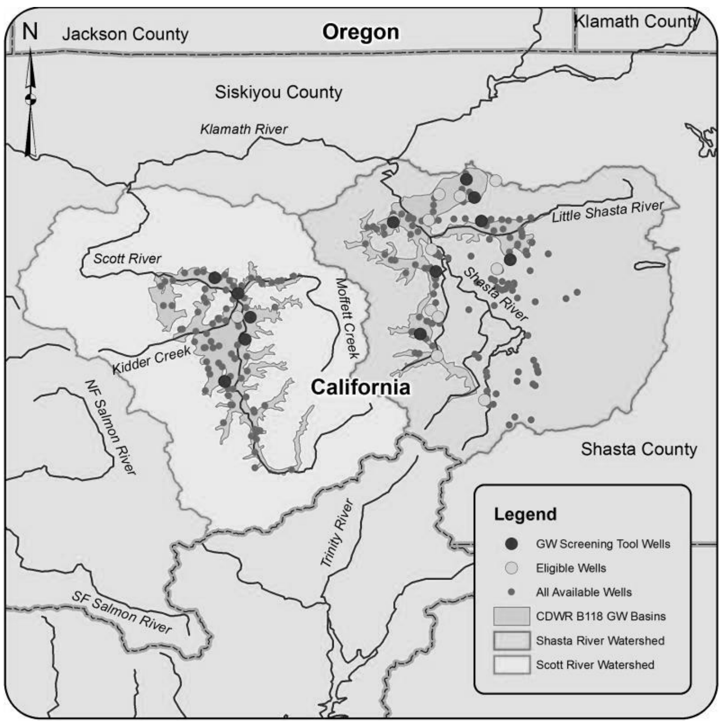



**Figure 3-14. Conceptual model of basin-scale groundwater fluctuations used in developing the groundwater screening tool**

The model domains for the Scott and Shasta Valleys correspond with groundwater basins defined by CDWR's Bulletin 118 (CDWR, 2003). CDWR Bulletin 118 was first created in the 1950s as a means for collection and evaluation of groundwater data throughout California. Bulletin 118 has been updated numerous times, with the latest update in 2003. Bulletin 118 has defined groundwater basins, including one each for the Scott and Shasta Valleys. Scott and Shasta Valley groundwater basins roughly correspond with the unconsolidated sand and gravel PNW Basin-fill aquifers from the USGS (2003) National Atlas of Principal Groundwater Aquifers[4] map. The Bulletin 118

[4] http://www.nationalatlas.gov/wallmaps.html#aquifers

groundwater basins define the model domain for the groundwater screening tools for the Scott and Shasta Valleys. These groundwater basins are illustrated in Figure 3-15.




Note: The map shows all available wells (grey), eligible wells3 (pink), and wells[3] used in development of the groundwater screening tools for both watersheds (red).

**Figure 3-15. Map of CDWR Bulletin 118 groundwater basins for the Scott and Shasta River basins**

Historical data were used to determine regression coefficients and to evaluate model performance over the historical period (1980–1999). For this study, historical groundwater elevation data averaged over each groundwater basin were used to fit the regression models. These data came from CDWR and USGS data archives. Monthly mean groundwater elevations were calculated from the available instantaneous measurements. Note that for the Scott and Shasta Valleys, well measurements typically occurred once in the spring and once in the autumn, and interpolated monthly time series were computed from these measurements. Well data were screened for individual outliers and analyzed to determine whether the groundwater elevations at the well are representative of the

average behavior of each groundwater basin (Scott and Shasta). Steps were taken to avoid potential biases due to variations in the period of record between wells, and outlier wells that are not representative of large-scale groundwater fluctuations within a basin. Additional details are provided in Appendix B, Supplemental Information for Assessment of Water Supply, regarding the sources of well data, methods for screening the data, and methods to account for potential biases in well records. Inputs of precipitation, evaporative demand, and streamflow were computed based on VIC model simulations, aggregated to a monthly timestep and averaged over each groundwater basin. Demands such as agricultural and municipal, domestic, and industrial demand were developed based on available data described in detail in Appendix B, Supplemental Information for Assessment of Water Supply. Note that aquifers outside of CDWR Bulletin 118 and well data not archived by CDWR or USGS were not considered as part of this modeling study, which may present limitations in the applicability of the modeling tools to simulate basin-wide behavior.

### 3.4.5 Present Availability and Historical Trends – Scott and Shasta Valleys

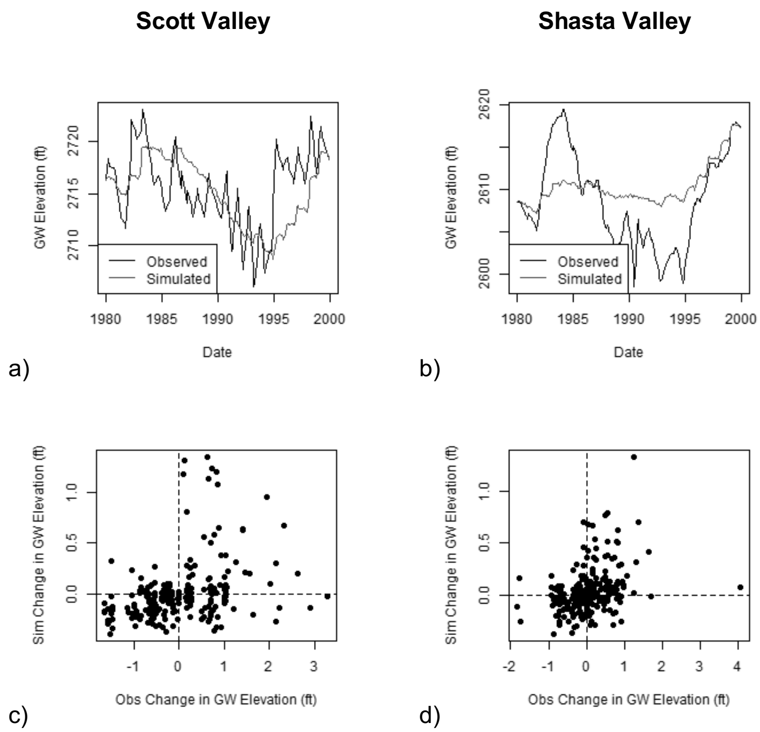
The groundwater screening tool was applied to the groundwater basins in the Scott and Shasta watersheds that were defined by CDWR Bulletin 118 (CDWR, 2003) and are shown on Figure 3-15. There is one defined groundwater basin for each of the watersheds. The screening tools were fit using a linear regression model to the collected observed data (see Equation 1 in Appendix B, Supplemental Information for Assessment of Water Supply). The models were then verified by exploring variations of the groundwater elevation input data. The regressions were tested to ensure that well data used most closely represented basin-wide behavior. Correlations of observed groundwater elevation with individual model inputs were explored and statistically significant correlations (at the 95th percentile confidence level) were found between observed groundwater elevation, precipitation, and runoff for some wells (but not all), indicating that groundwater levels in the Scott and Shasta Valley CDWR Bulletin 118 aquifers are related to climatic fluctuations.

> **Historical Groundwater Availability – Scott and Shasta Valleys**
>
> The statistical groundwater screening tools may be applicable for evaluating the relative impacts of climate change amounts in the central and southern parts of the basin.

Figures 3-16 (a) and (b) illustrate observed and simulated basin-averaged groundwater elevation for the Scott and Shasta groundwater basins, respectively, for the period 1980–1999. The figures show that the groundwater screening tools capture the larger frequency fluctuations (i.e., multi-year trends) in groundwater

elevation, but are not able to resolve finer interannual fluctuations. Both groundwater basins experienced declines in groundwater elevation during the late 1980s and early 1990s on the order of about 20 feet, corresponding with lower precipitation and streamflow during that period. Observed groundwater elevations in the Scott Valley have ranged between about 2,705 feet and 2,725 feet, while observed groundwater elevations in the Shasta Valley have ranged between about 2,600 feet and 2,620 feet. Interannual fluctuations may be driven by local-scale non-linear processes that are not represented in the basin-scale screening tool, or by management activities (for example, pumping) that are not included in this analysis.

Figures 3-16 (c) and (d) illustrate observed change in groundwater elevation versus simulated change in groundwater elevation. They graphically show the data points on which the linear regressions for the groundwater screening tools are based. Model fit statistics summarized in Table 3-4 show that for both the Scott and Shasta Valleys, the screening tools are able to explain a little more than 10 percent of the variance in the data (coefficient of determination, or $R^2$, of 0.11 and 0.12, respectively, for Scott and Shasta groundwater basins). A more robust model would have higher $R^2$ values. The degree of model fit indicates that the tool may be applicable for evaluating the relative impacts of climate change, but is not applicable for evaluation of short-term management decisions. In the future, additional and improved data sources may help to improve model fit and thereby the applicability of the tool for a range of purposes.




Note: (a) groundwater elevation for the Scott groundwater basin; (b) groundwater elevation for the Shasta groundwater basin; (c) groundwater elevation change for the Scott groundwater basin; (d) groundwater elevation change for the Shasta groundwater basin

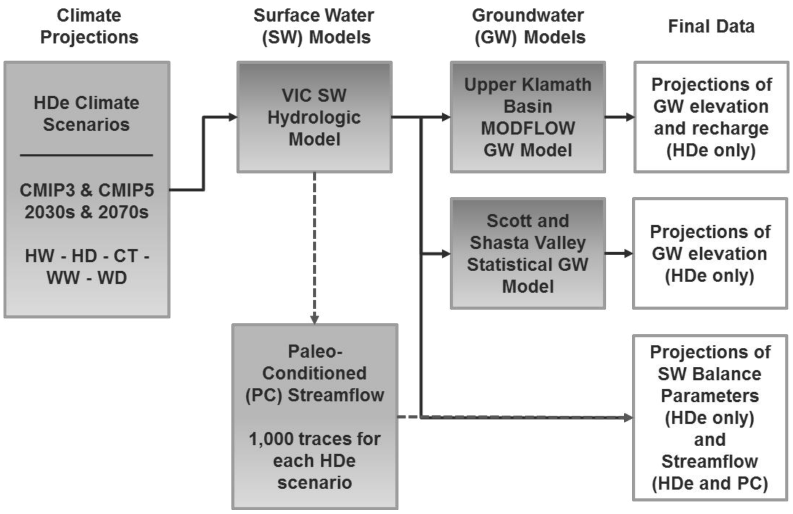
**Figure 3-16. Simulated and observed Scott and Shasta basin groundwater elevations, as well as simulated and observed changes in groundwater elevations**

**Table 3-4. Summary of model fit for Scott and Shasta groundwater basin screening tools**

| Statistic | Scott Groundwater Basin | Shasta Groundwater Basin |
|---|---|---|
| **Multiple R2** | 0.11 | 0.12 |
| **Adjusted R** | 0.33 | 0.35 |
| **P-value** | 0.0000511 | 0.0000101 |
| **Residual Standard Error** | 0.838 | 0.5905 |

## 3.5 Effects of Climate Variability and Change on Supply

This section builds upon tools developed for assessment of historical supplies and provides a detailed discussion of the approach for developing and utilizing future climate scenarios to evaluate projected changes in surface and groundwater. A diagram illustrating the overall approach for evaluating the effects of climate change on water supply is provided in Figure 3-17. Details regarding data linkages between steps are provided in the next section.




Note: HDe refers to ensemble hybrid delta climate scenarios; PC refers to paleo-condition streamflow projections.

**Figure 3-17. Summary of approach for evaluating the effects of climate change on surface water and groundwater supplies**

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020 through 2049) and 2070s (represented by the mean from 2060 through 2089). In evaluating the effects of climate change on water supply, projections of future supply are commonly compared with that of a historical reference period. The historical reference period for the Klamath River Basin Study is 1970–1999. It should be noted that historical climate has not changed steadily through the 20th century. Basin average temperature has increased from the 1970s through the rest of the century, following an approximate 40-year period of relatively steady temperatures. Basin annual precipitation has fluctuated considerably during the past century, but was relatively steady from the 1940s

through the rest of the century (Reclamation, 2011c). Figure 3-7 illustrates historical trends from 1950 through 1999.

### 3.5.1 Approach

As a step toward greater understanding of the implications of climate change on the Klamath River Basin, this section first describes the approach for development of climate scenarios for the Klamath River Basin Study water supply assessment, followed by discussions of approaches for evaluation of climate change impacts on surface and groundwater supplies. With respect to surface water, the assessment focuses on projected changes in snowpack, timing and quantity of runoff, ET and soil moisture, and low streamflow periods that have major implications for fish and wildlife and the livelihoods of basin residents. With respect to groundwater, the assessment focuses on projected changes in groundwater recharge and discharge, as well as overall changes in groundwater elevations.

#### *3.5.1.1 Climate Projections*

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades as opposed to days or weeks. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings, both natural (such as volcanic eruptions, solar variations) and anthropogenic (such as changing atmospheric composition and land-use change). Climate variability describes deviations from mean climate that may be due to natural internal processes or to variations in natural or anthropogenic forcings. Natural variability includes multi-year cycles in climate such as El Niño and La Niña, as well as cycles that can occur on even longer time scales (for example, the PDO). Changes in climate due to natural variability will continue to occur in the future, along with changes due to increased greenhouse gas concentrations from human activities. Climate change may be differentiated from climate variability as the persistence of anomalous conditions.

**Climate Projections**

The Klamath River Basin Study utilizes climate projections from World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) and Phase 5 (CMIP5).

The state of practice for evaluation of the long-term availability of water supply is to incorporate a range of approaches to characterize past and projected climate. The approaches may include use of paleo-conditioned climate data and use of projections from general circulation models (GCMs). Paleo-conditioned climate data are developed from long-term climatic records (such as tree rings, pollen, etc.) that have been used to capture the natural variability of climate over thousands of years.

Another approach involves downscaling information (in space and time) from native scale GCM resolution to a finer resolution suitable for watershed-scale climate change impact studies. This can be done using dynamical downscaling, which uses GCM output to define boundary conditions for a finer scale regional climate model, or statistical downscaling, which uses historical data as a way of statistically mapping GCM scale information to a finer resolution. Statistical downscaling may involve delta method experiments, which compute period change values based on GCMs and apply them as perturbation factors to historical data. Numerous variations exist within these three categories and there are also approaches that are hybrids of these categories.

The Klamath River Basin Study relies on data and modeling from Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). In that effort, Reclamation developed a consistent database of climate and hydrologic projections, with a focus on the 17 western states that fall within Reclamation's management domain. These projections are based on simulations from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3; Meehl et al., 2007), which are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007). Projections based on Phase 5 of the same model intercomparison project (CMIP5) reflect improvements in modeling of the Earth system since the CMIP3 effort and revised scenarios of global growth and greenhouse gas emissions. These simulations, which were made available in 2011, are summarized in IPCC's Fifth Assessment Report (Taylor et al., 2012). Both sets of projections, CMIP3 and CMIP5, are utilized as part of the Klamath River Basin Study water supply assessment.

Details regarding the approach for use of climate projections and development of climate scenarios for the Klamath River Basin Study are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, Figure 3-18 illustrates the overall approach for downscaling GCM projections to a finer spatial scale. The figure shows that a similar approach is taken regardless of the choice of CMIP3 or CMIP5 simulations: namely, emissions scenarios are incorporated into GCM simulations. These simulations are bias corrected at the resolution of the GCM and then statistically downscaled to the resolution of the Klamath River Basin Study hydrology models. Bias correction allows for the removal of systematic biases from GCM simulations, based on historical regional climate datasets derived from observations.

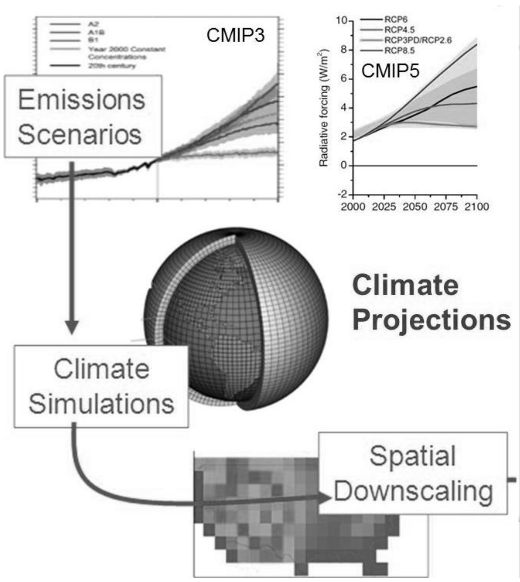



**Figure 3-18. Downscaling elements**

### *3.5.1.2 Deriving Climate Change Scenarios from Climate Projections*

The high number of climate projections from CMIP3 and CMIP5 (on the order of hundreds of realizations) make their direct use in long term planning studies cost prohibitive in many cases. The Klamath River Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes the available suite of climate projections to derive a smaller number of climate change scenarios to inform long term planning.

The Klamath River Basin Study primarily utilizes climate scenarios that are derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d). The scenarios are developed based on both CMIP3 and CMIP5 statistically downscaled GCM projections, as these are considered equally likely potential climate futures at this time. Details regarding the approach for deriving climate scenarios from CMIP3 and CMIP5 climate projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, a brief overview is provided below.

The hybrid delta method approach for developing climate scenarios involves perturbing historical climate (precipitation and temperature) by change factors computed as the change in precipitation and temperature by month between a chosen future planning horizon and a baseline historical period (Reclamation, 2010). Change factors may be developed for each available downscaled climate projection (CMIP3 or CMIP5) or may be developed based on ensembles of climate projections. The Klamath River Basin Study utilizes an ensemble of climate projections based on both CMIP3 and CMIP5.

## HDe Climate Scenarios

Ensemble hybrid delta climate scenarios representing five quadrants of precipitation and temperature change (warm wet, warm dry, central tendency, hot dry, hot wet) are used to encompass a range of possible climate futures for two future time horizons, the 2030s and the 2070s.

The HDe method involves defining a climate change scenario based on pooled information from a collection of climate projections. Use of a sufficiently large number of projections (commonly called an ensemble) pooled together reduces the signal of internal climate variability (which is inherent in each single projection), which may be misinterpreted as climate change. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios. These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT).

Historical precipitation and temperature are mapped, using a quantile mapping technique, onto the bias corrected GCM data to produce a set of transformed observations reflecting future conditions. The entire observed time series of temperature and precipitation at each hydrologic model grid cell is perturbed in this manner, resulting in a new time series that has the statistics of the bias corrected GCM data for the future period, but preserves the time series and spatial characteristics of the gridded temperature and precipitation observations.

The HDe scenarios for the Klamath River Basin Study culminate in a total of 20 scenarios, including two future time horizons (2030s and 2070s), five quadrants of projected change (HW, HD, CT, WW, and WD), and two sets of projections (CMIP3 and CMIP5). Each of these scenarios resemble the historical inputs of daily precipitation and temperature (minimum and maximum) to the VIC surface water hydrologic model in format and period of record because they are all perturbations of historical time series. Windspeed, the remaining required input to the VIC model, was assumed not to change between historical and future time periods. This assumption is in part due to the coarse resolution of historical windspeed data used in the Maurer et al. (2002) historical meteorological dataset

and the associated high level of uncertainty in the data. However, to provide some context, Pryor et al. (2012) found some evidence of lower intense windspeeds in the western U.S. for the 2041–2062 period compared with 1979–2000 from regional climate model simulations.

Figure 3-19 summarizes projected changes in precipitation (a) and temperature (b) by month according to the five HDe climate scenarios for each time period in relation to the full suite of CMIP3 and CMIP5 projections by month. This figure illustrates that the derived climate scenarios generally span the range of projected future precipitation and temperature by the greater number of climate projections. However, with respect to precipitation change, it appears the HDe scenarios project a greater tendency toward increased precipitation during summer months (August, in particular) than the raw climate projections indicate. This is likely due to the fact that the HDe projections are based on projected annual changes in precipitation, not seasonal or monthly changes. Projected annual changes in precipitation appear to be influenced more by increases in winter precipitation.

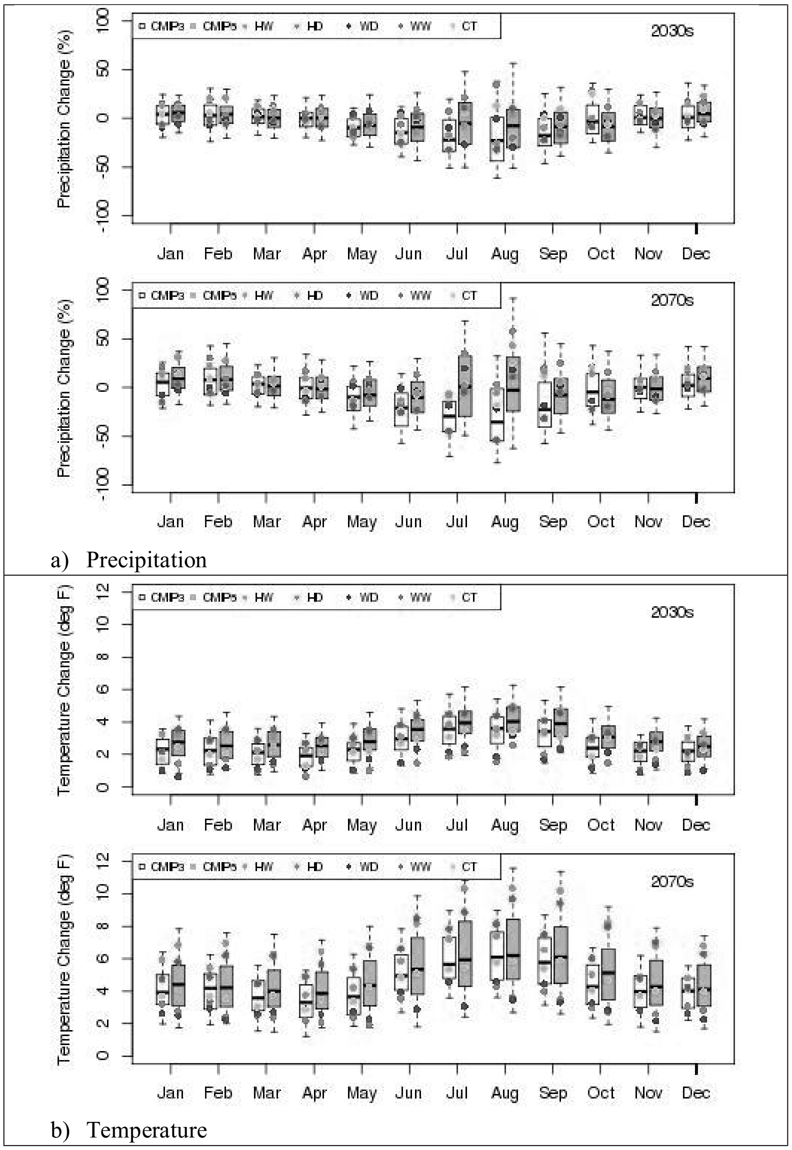



**Figure 3-19. Changes in mean monthly precipitation and temperature**

HDe scenarios have a number of distinguishing features, with associated strengths and weaknesses. One weakness of this approach is that analysis of climate change impacts is limited to the future time horizons chosen when developing precipitation and temperature change factors. Another weakness is that the scenarios do not incorporate projected changes in drought variability or sequencing of storm events. One key strength of the HDe approach is that the time sequence of projected future storm events matches historical climate data, facilitating direct comparison between the observations and future scenarios. The HDe approach is suitable for water resources planning at both daily and longer time scales, supports analysis of daily hydrologic extremes such as flood and drought intensity, and provides consistency across a range of spatial scales (Hamlet et al., 2010).

#### *3.5.1.3 Deriving Paleo-Conditioned Streamflow Projections*

Understanding drought variability is critical to managing water resources across the western U.S. The HDe scenarios described in the previous section may be used as input to surface and groundwater hydrologic models to evaluate changes in the water balance. As mentioned, HDe scenarios are perturbations of the historical record that reflect the statistics of future climate over some chosen time period. As a result, they do not explore the possibility of changes in drought variability (i.e., length or severity of drought periods and wet periods).

Paleo-climate information derived from tree rings or other proxies provides a greater context for sequencing and duration of wet and dry periods than the historical record can provide, often going back hundreds of years. The paleo-conditioned streamflow projections described in this section achieve a blend of projected climate information derived from GCMs and paleo-climate information.

To develop a long-term understanding of drought variability across North America, Cook et al. (2004) developed an extended record of summer time PDSI (Palmer Drought Severity Index) using tree-ring chronologies. This extended PDSI record for North America is available as a gridded (2.5 degrees latitude by 2.5 degrees longitude) timeseries, nearly 200 miles on a side, that dates back nearly 2000 years in some locations. Availability of this extended gridded PDSI record provides an opportunity to analyze regional drought and wet spell characteristics.

For the Klamath River Basin Study water supply assessment, a representative grid location (see Figure 3-20) from the extended gridded PDSI archive was used to analyze long-term wet and dry spells in the Klamath River Basin. Adjacent grid locations provided similar results. The specific location of the PDSI grid used has a center with latitude 42.5 degrees N and longitude 120.0 degrees W., shown by a green triangle in Figure 3-20. The PDSI time-series used from this grid extended from 1400 through 1999.

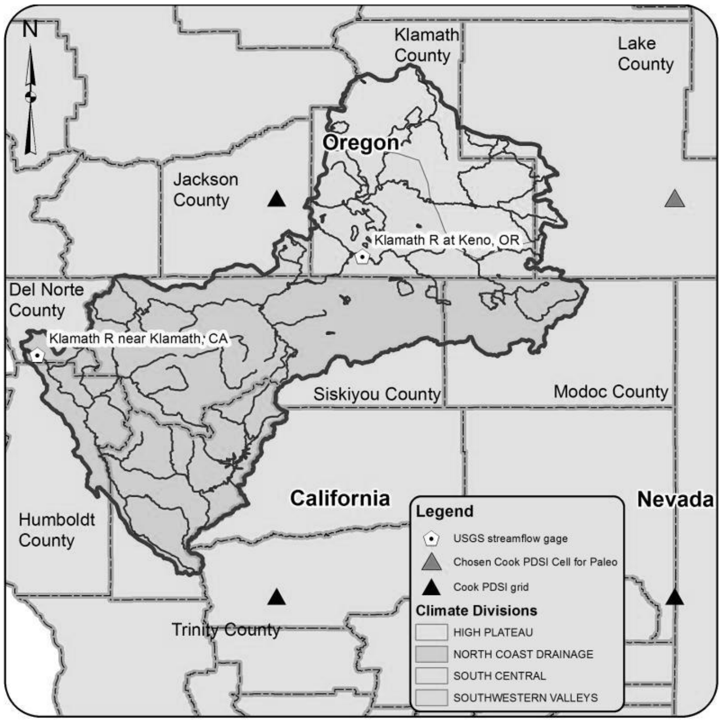



**Figure 3-20. Overview map of the Klamath River Basin with Cook PDSI grid and two USGS streamflow gages used in the analysis of paleo-hydrology: Klamath River near Klamath, CA and at Keno, OR**

To understand the time-varying nature of wet and dry spells, the PDSI index can be used to determine the probability of regional hydrology shifting from one state to another. In this study, the Klamath River Basin was defined to be either in dry state when the summer time PDSI value in a given year was less than 0 (negative PDSI corresponds to dry conditions), or in a wet state when PDSI was greater than 0 (positive PDSI values correspond to wet conditions). Based on the defined states, probabilities may be derived for the likelihood of transitioning from one state to another. Flow magnitudes can be assigned based on the probabilities, which allows for evaluation of historical streamflow over the instrumental record and projected streamflow compared with the paleo period.

The results for the Klamath River indicate that paleo-conditioned historical simulations show reduced lengths and volumes of wet periods. Results also show droughts of reduced length and deficit, demonstrating that just changing the ordering of flows over the historical period results in periods of both reduced droughts and surpluses. Furthermore, the wet period volumes could be quite a bit lower than what has been historically available, according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than is shown in the recent instrumental record.

**Paleo-Conditioned Streamflow Projections**

Wet period volumes could be quite a bit lower than what has been historically available according to the instrumental record. Similarly, droughts were also less severe over the last 6oo years than what is shown in the recent instrumental record.

Paleo-conditioned streamflow projections are not carried throughout the Klamath River Basin Study water supply assessment and subsequent phases of the Basin Study for two primary reasons. First, analysis of paleo-conditioned streamflow, including historical and HDe scenarios, suggests that periods of drought and surplus over the paleo record are within the range of variability experienced for the historical 1950–1999 period. Thus, including paleo-conditioned projections of streamflow, and potentially other variables, would be computationally time-intensive yet would not yield additional information. Second, because the Klamath River Basin lacks an integrated surface water – groundwater model, there would be inconsistencies in data linkages between models that make use of paleo-conditioned projections infeasible. For example, the groundwater models rely on inputs of climate, recharge, and streamflow, yet paleo-conditioned projections of climate and water balance variables do not exist to correspond with the paleo-conditioned streamflow projections. Paleo-conditioned streamflow projections may provide a greater context for future water supply projections, but are not directly used in further analysis.

#### *3.5.1.4 Surface Water Hydrology*

Assessment of climate change impacts on surface water supply was conducted using HDe (ensemble informed hybrid delta) scenarios and was informed by paleo-conditioned streamflow projections. The overall approach is described below and is illustrated in an overview diagram in Figure 3-21.

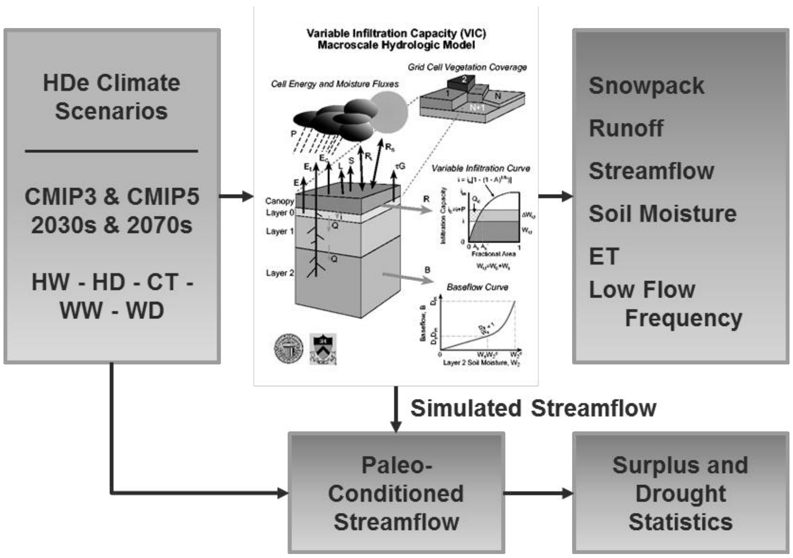



**Figure 3-21. Approach for assessment of projected surface water supplies**

HDe scenarios may be directly used by the VIC model to generate associated projections of snowpack, runoff, and other elements of the water balance. In evaluating the implications of climate change, the water supply assessment first provides comparisons of results based on CMIP3 and CMIP5 projections with respect to mean annual precipitation and temperature, April 1 SWE, and mean annual runoff.

Following the comparison of CMIP3 and CMIP5 results, the assessment discusses projected changes in seasonal precipitation and temperature, snowpack on April 1, mean annual runoff, spring runoff, June 1 soil moisture, mean annual ET, mean monthly streamflow at select sites, annual runoff timing, and changes in the 7 day low flow with 10 year recurrence interval (also called 7Q10). This part of the assessment focuses on results using CMIP5 projections (unless otherwise noted) for the two future time horizons (2030s and 2070s); however, figures based on CMIP3 projections, corresponding to those presented in the water supply assessment, are presented and briefly discussed in Appendix B, Supplemental Information for Assessment of Water Supply.

Drought and surplus statistics are evaluated based on the developed paleo-conditioned streamflow traces. Paleo-conditioned streamflow relies on projected natural streamflow output from the VIC model as well as statistics developed from the analysis of the paleo-record. Projected natural streamflows from the VIC model are resampled 1,000 times for each of the five HDe climate change scenarios, future time horizons, and projection types (CMIP3 and CMIP5) to develop statistics of projected surplus and drought volumes and lengths.

#### *3.5.1.5 Groundwater Hydrology*

This section describes the approaches for utilizing climate change scenarios to evaluate projected changes in groundwater recharge, discharge, and elevations in three groundwater basins of the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys.

**Upper Klamath Basin**

The effects of projected climate on groundwater in the Upper Klamath Basin were analyzed using the existing MODFLOW finite-difference groundwater model developed by Gannett et al. (2012). For this study, the model was driven by HDe climate scenarios and surface water hydrologic projections, and results were compared with the historical simulation (presented and summarized in Section 3.4.3, Present Availability and Historical Trends – Upper Klamath Basin) to evaluate results due to changes in climate alone, excluding any impact due to changes in groundwater demand (i.e., pumping). Paleo-conditioned streamflow projections were not taken through the Upper Klamath Basin groundwater impacts analysis because stream stages are held constant in the MODFLOW simulations and Gannett et al. (2012) determined that streams generally have very little net exchange with the groundwater system. The avenues for incorporation of projected surface water inputs into the MODFLOW model are listed below, and they do not have associated paleo-conditioned projections.

1. Projected maximum ET for each of the five HDe climate change scenarios, where maximum ET is represented as PET less actual ET as computed from VIC surface water hydrology model output
2. Projected groundwater recharge for each of three recharge zones for each of the five HDe climate change scenarios

The methodology for developing each type of projected MODFLOW input is described briefly below and illustrated in an overview diagram in Figure 3-22.

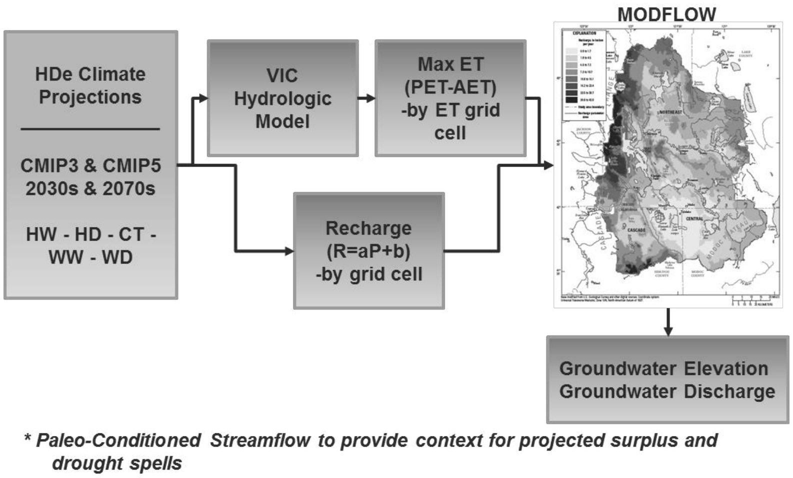



**Figure 3-22. Approach for assessment of projected groundwater supplies in the Upper Klamath Basin**

*Maximum Evapotranspiration Rate*

Evapotranspiration is modeled in the Upper Klamath Basin MODFLOW model (Gannett et al., 2012) using the EVT, or evapotranspiration package. One of the principal input parameters is the maximum ET rate associated with groundwater. Gannett et al. (2012) computed this parameter based on output from the PRMS surface water hydrology model. Specifically, this parameter is computed as the difference between PET and actual ET. This difference represents the amount of potential demand that could be supplied by groundwater and is not supplied by precipitation.

In this study, the VIC model was used to generate meteorological inputs for future MODFLOW simulations. The VIC model was chosen, as opposed to PRMS, because it is available for the entire Klamath River Basin, is widely used for studies of climate change impacts, and was used in the hydrologic modeling and development of hydrologic projections as part of Reclamation's West-Wide Climate Risk Assessment (Reclamation, 2011d). Maximum ET was computed on a quarterly (seasonal) basis from VIC simulations for the five HDe climate change scenarios. Quarterly maximum ET computed from VIC simulations (at 1/8$^{th}$ degree spatial resolution) was compared with historical maximum ET used in the historical MODFLOW simulation, aggregated to VIC's spatial resolution. Quarterly (stress period) change factors were developed at the VIC model spatial resolution and factors were applied to historical maximum ET from MODFLOW for each MODFLOW cell within a VIC grid cell. The reason for using change factors and not directly applying projected maximum ET from the VIC model is

to avoid introducing bias due to the differing model constructs (i.e., PRMS generated historical maximum ET while VIC generated projected maximum ET).

*Groundwater Recharge*
The Gannett et al. (2012) historical groundwater simulation uses as input historical groundwater recharge computed by the PRMS model. Because the VIC model was used to generate inputs for future projection simulations, and because historical simulated recharge from VIC may be quite different from recharge used in the historical MODFLOW simulation (derived from the PRMS hydrologic model), a relationship was developed between historical annual precipitation (gridded dataset developed by Maurer et al. [2002] was used in development of surface water hydrology for this study as well as future climate scenarios) and historical annual recharge.

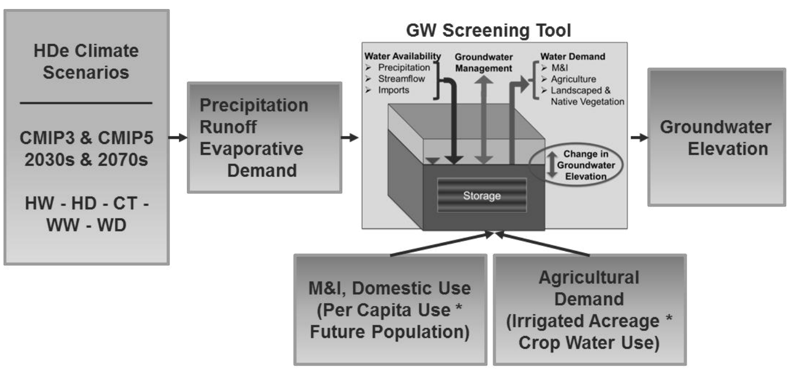
Although alternate relationships were explored in this study, a linear relationship between precipitation and recharge appeared to best represent the data. Such a relationship was developed using annual recharge and precipitation (at the spatial resolution of the VIC model), aggregated by recharge zone. Using the developed relationships between annual recharge and precipitation (by recharge zone) based on historical data, the same relationship was applied to each of the five HDe climate change scenarios of precipitation for two future time periods (2030s and 2070s) and for CMIP3 and CMIP5 projections. As a result, corresponding projections of recharge were developed at the VIC model resolution. These projections were used to generate annual change factors (based on ratios between projected recharge and MODFLOW historical), which were then applied to historical recharge uniformly over all MODFLOW grid cells within a corresponding VIC model grid cell.

*Caveats*
It should be noted that the described approach for developing projected surface water inputs to the Upper Klamath Basin MODFLOW model may introduce errors in the groundwater balance due to inconsistently developed inputs. For example, recharge and maximum ET projections were developed using established relationships between projections based on HDe scenarios and historical values used in MODFLOW historical simulations. Hence, they were not developed via an integrated surface water model. Despite the use of potentially inconsistent methodologies, this approach provides the best available estimates of projected surface inputs to the groundwater system.

**Scott and Shasta Valleys**
Projections of future groundwater elevation may be computed for the Scott and Shasta Valleys using the groundwater screening tools developed and described in Section 3.4, Historical Groundwater Availability. Similar to the Upper Klamath Basin, perturbed historical inputs representing projected conditions were used by the models to generate projections of groundwater elevation. Future projections were incorporated for climate and water balance input terms, as well as municipal, domestic, and industrial demand with respect to projected population.

Agricultural demand was left unchanged for the water supply assessment in order to focus on the impacts of climate change on groundwater elevation, and not changes in agricultural demand. Variations in historical agricultural demand are incorporated into historical groundwater elevations used to develop relationships in the computation of groundwater response. However, projected changes in temperature and precipitation will affect agricultural demand, which may markedly affect groundwater levels beyond what was experienced historically. In the discussions of climate change impacts on water demand in the watershed and associated risks and system reliability (Chapters 4 and 5 of this Klamath River Basin Study report, respectively), we address projected changes in agricultural demand and how the watershed may be impacted by the compounded stresses associated with climate change (with and without management adaptations).

Specific projected inputs to the groundwater screening tools for the Scott and Shasta Valleys are further described below. An overview diagram illustrating how projected inputs are incorporated into the groundwater screening tools is provided in Figure 3-23.




** Paleo-Conditioned Streamflow to provide context for projected surplus and drought spells*

**Figure 3-23. Approach for assessment of projected groundwater supplies in the Scott and Shasta Valleys**

Future projections of monthly mean precipitation and daily mean temperature (surrogate for evaporative demand) computed over the groundwater basins were input to the groundwater screening tools for each basin. These climate scenarios were based on the five HDe climate change scenarios for two future time horizons (2030s and 2070s) as well as for projections based on both CMIP3 and CMIP5. Similar projections of mean monthly runoff over each of the groundwater basins were also input to the models.

It should be noted that the approaches described above for developing projected surface water inputs to the Scott and Shasta Valley groundwater screening tools (including precipitation, temperature, and runoff) are compatible. These inputs rely on HDe climate scenarios themselves (in the case of precipitation and temperature) or outputs generated by the VIC model (runoff) whose simulations rely on HDe climate scenarios.

Municipal, industrial, and domestic water demand, which was computed based on the product of per capita water use and population, was perturbed according to projected population growth. Per capita use was assumed to remain constant. Projected population for each of the two future time horizons (2030s and 2070s) was computed by assuming a percent increase in population equal to the percent change between 1990 and 2000, which was documented by the 2000 Census.[5] For the Scott Valley this was +1.93 percent, while for the Shasta Valley it was +2.01 percent over ten years. The mean of projected population 2020–2050 was used to represent 2030s population, while the mean of projected population 2060–2080 was used to represent 2070s population. Additional scenarios of population growth were not considered as part of the water supply assessment; however, additional scenarios may be considered in subsequent stages of the Klamath River Basin Study as part of the analysis of management alternatives and/or adaptation strategies.

As previously mentioned, agricultural water demands were not modified as part of the evaluation of climate change impacts on groundwater elevations in the Scott and Shasta Valleys. The primary reason changes in agricultural demand were not considered here is that detailed analysis of the implications of projected agricultural demand is part of the assessment of current and future water demands in Chapter 4.

## 3.6 Comparison between CMIP3 and CMIP5

Projections of climate as well as surface water and groundwater hydrologic variables were summarized using both CMIP3- and CMIP5-based projections to understand whether these projections provide a similar view of future conditions. Few studies exist to provide guidance on whether the more recent CMIP5 projections ought to supersede those from CMIP3, whether they are similar enough that one or the other may be used, or whether they ought to be used collectively in impacts assessments. The intent of the Klamath River Basin Study water supply assessment is not to provide such guidance, but instead to evaluate the impacts of climate change using both sources of projections to provide the most comprehensive understanding possible of projected changes in water supply in the watershed.

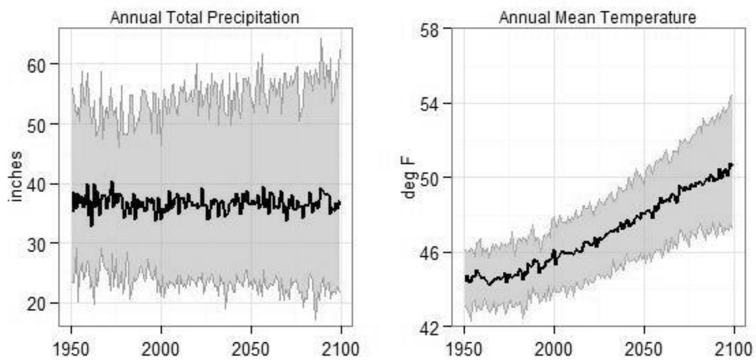
[5] http://www.ncdc.noaa.gov/climate/research/population/

### 3.6.1 Climate

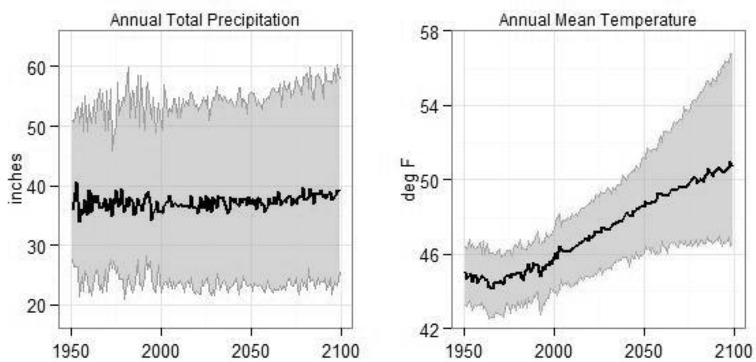
The basis for the five HDe climate change scenarios of precipitation and temperature (minimum and maximum) used throughout the Klamath River Basin water supply assessment is a suite of monthly statistically downscaled GCM simulations, based on CMIP3 and CMIP5 projections. As described in detail in Section 3.5.1.1, Climate Projections, HDe scenarios are generated by computing change factors between designated future time horizons (in this case the 2030s and 2070s) and a designated historical period (in this case 1970–1999).

Figure 3-24 illustrates the envelopes of projected mean annual precipitation and temperature as they evolve through time (i.e., light red on the top panel for temperature and light blue on the bottom panel for precipitation). All projections show that the region will become warmer during the 21st century, with greater uncertainty in annual temperature farther into the future as shown by the widening swath of projections. Annual precipitation in the Klamath River Basin is projected to increase slightly through time. However, it should be noted that this slight projected increase (both for CMIP3 and CMIP5 projections) is within the range of historical variability in precipitation from year to year. In contrast, for temperature, the median projection shows that temperatures will exceed the range of historical year to year variability by about 2050.

A comparison of CMIP3 and CMIP5 projections shows that trajectories through time appear similar; however, the range of projected precipitation is similar between the two types of projections, while projected temperature appears greater with CMIP5 projections. The larger projected range in projected temperature is likely due to the consideration of the full range of emissions scenarios for both CMIP3- and CMIP5-based projections. As shown in Figure 3-24, the range of projected global warming is greater for CMIP5 scenarios than for CMIP3.




a) **CMIP3**




**b) CMIP5**

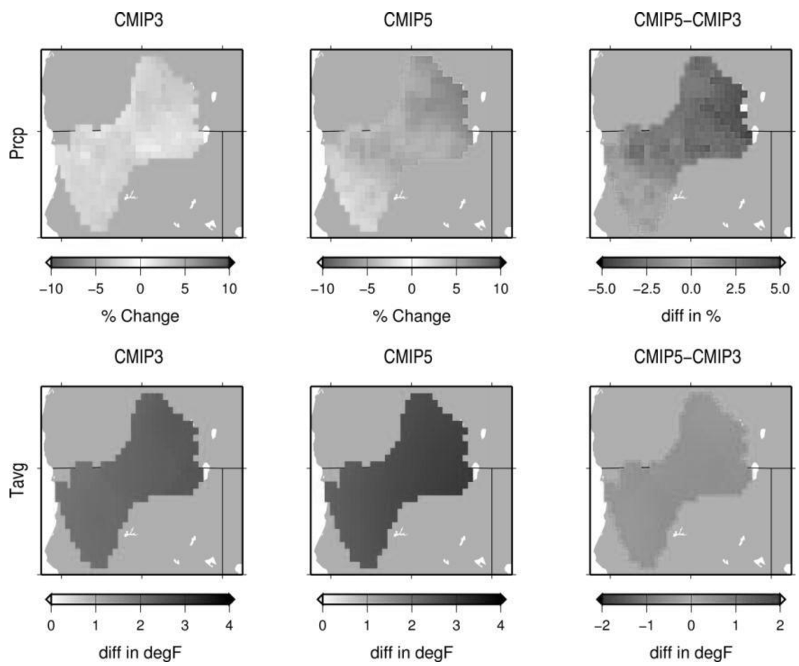
Note: The top row (a) and bottom row (b) illustrate the range of CMIP3 projections and CMIP5 projections, respectively. The black line in each panel shows the median of annual projections, while the colored band represents the range of all GCM projections (112 for CMIP3 and 234 for CMIP5).

**Figure 3-24. Summary of statistically downscaled GCM projections of mean annual precipitation and temperature from 1950 to 2100**

Figure 3-25 shows projected changes in mean annual precipitation (in percent) and average temperature (in degrees F) for the 2030s, compared with the historical baseline (1950–1999), using both CMIP3- and CMIP5-based HDe scenarios, while Figure 3-26 shows similar projections for the 2070s. It should be noted that these projections do not reflect information from the paleo record, as paleo-conditioned projections only correspond with streamflow. The projections shown in the figures represent the central tendency derived using the HDe approach. Each figure shows projections based on CMIP3 in the left panel,

projections based on CMIP5 in the middle panel, and the difference between CMIP5 and CMIP3 in the right panel.

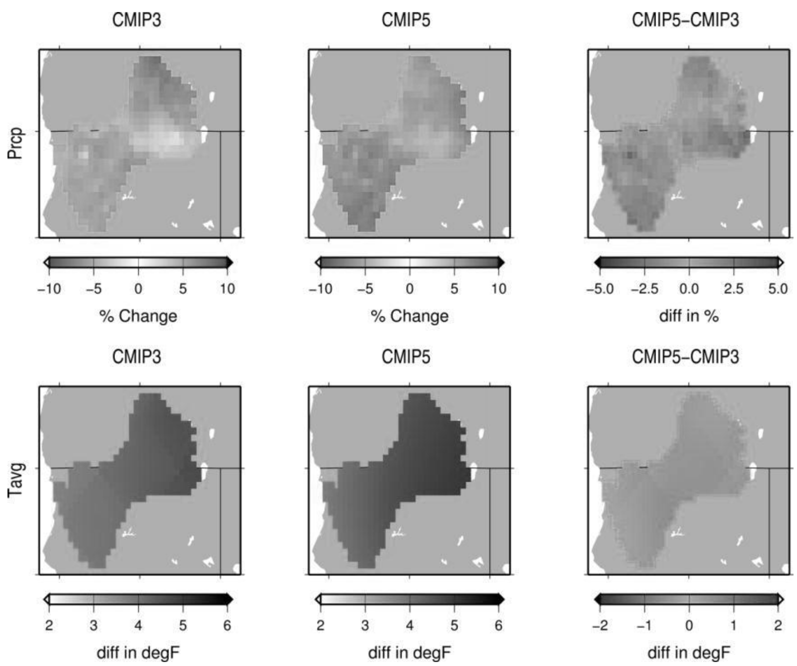
Projected changes in precipitation and temperature are positive for both CMIP3 and CMIP5 for the 2030s and 2070s. As can be seen in Table 3-5, which summarizes spatially averaged projected changes for both time horizons and over three dominant Klamath River Basin climate divisions as well as the basin as a whole, there are notable differences in the magnitude of projected change.




Notes:

1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

**Figure 3-25. Comparison of percent change (2030s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5**




Notes:
1. Prcp = mean annual precipitation; Tavg = mean daily average temperature
2. The right-hand column illustrates the difference between the first two columns, i.e. between CMIP5 projections and CMIP3 projections.

**Figure 3-26. Comparison of percent change (2070s to historical) in mean annual precipitation and mean daily average temperature for central tendency HDe scenarios, based on CMIP3 and CMIP5**

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For the 2030s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the North Coast Drainage, which is located at the California portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 4.1 percent increase in mean annual precipitation, while CMIP3-based scenarios indicate a 2.4 percent increase by the 2030s. CMIP5-based scenarios are noticeably wetter than CMIP3 in the eastern portions of the High Plateau and South Central climate divisions. However, CMIP5-based scenarios are noticeably drier in the southernmost portion of the watershed, as previously mentioned. With respect to mean annual average temperature for the 2030s, CMIP5 projections indicate a greater increase in temperature than CMIP3 for all spatial domains considered (see Figure 3-2), although the projections are not substantially different. Projected temperatures basin-wide for the 2030s central

tendency show an increase of 2.2 degrees F for CMIP3 and 2.7 degrees F for CMIP5.

For the 2070s, CMIP5 projections generally suggest greater increases in mean annual precipitation than CMIP3 projections for all summarized domains except the High Plateau, which is located at the northernmost portion of the basin (refer to Figure 3-2). Looking basin-wide, CMIP5 projections indicate a 6.1 percent increase in mean annual precipitation, while CMIP3 projections indicate a 5.2 percent increase by the 2070s. With respect to mean annual average temperature for the 2070s, CMIP5 projections indicate a greater increase in temperature than CMIP3 projections for all spatial domains, which is similar to results for the 2030s. Projected temperatures basin-wide for the 2070s central tendency indicate an increase of 4.2 degrees F for CMIP3 and 4.5 degrees F for CMIP5.

Although the magnitude differences are quite similar between CMIP3 and CMIP5 for precipitation and temperature for each future time horizon (central tendency), the spatial differences between CMIP3 and CMIP5 are interesting (see the right panels of Figures 3-25 and 3-26). For the 2030s, CMIP3 projections show less increase in precipitation that CMIP5 in the lowermost portion of the Klamath River Basin, while also showing a larger increase in the easternmost portion of the basin. For the 2070s, CMIP3 projections show less increase in precipitation in the Oregon portion of the basin than CMIP5 projections, while in most other parts of the basin CMIP5 projections show greater increase. The spatial differences between CMIP3- and CMIP5-based scenarios may be due to internal variability in the model simulations, and therefore the spatial patterns should be viewed collectively as potential future conditions.

## CMIP3 and CMIP5 Comparison – Precipitation and Temperature

Ranges of projected precipitation appear similar while ranges of temperature appear greater with CMIP5 than with CMIP3 scenarios. Spatial differences between CMIP3 and CMIP5 scenarios may be due to internal variability in the model simulations and HDe scenario development. By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.

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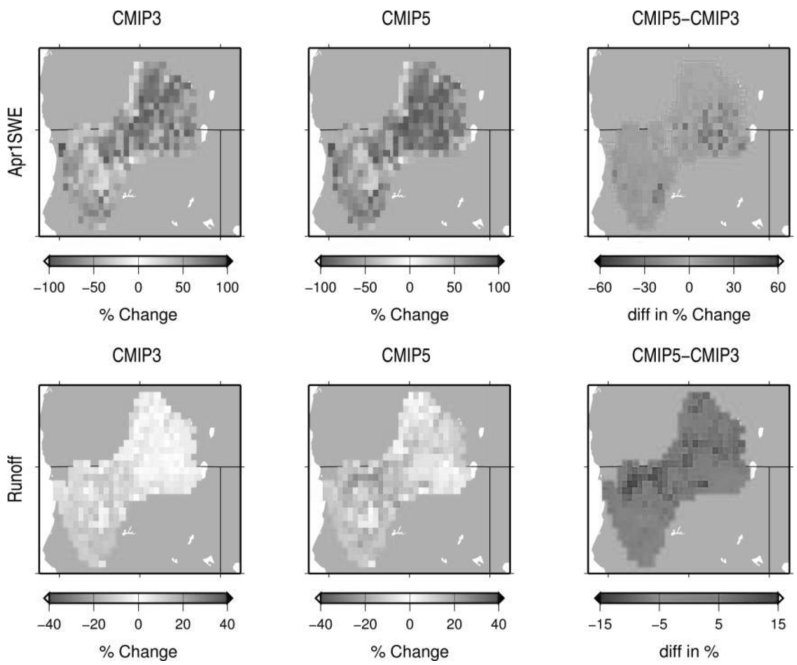
**Table 3-5. Summary of projected changes in mean annual precipitation and average temperature for the 2070s, compared with the historical baseline**

**(1950–1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions**

| Climate Division | Basinwide | North Coast Drainage | South Central | High Plateau |
|---|---|---|---|---|
| **2030s** | | | | |
| Prcp, CMIP3 | +2.4 % | +2.3 % | +2.4 % | +2.7 % |
| Prcp, CMIP5 | +4.1 % | +3.6 % | +5.4 % | +5.8 % |
| Tavg, CMIP3 | +2.2 degF | +2.2 degF | +2.3 degF | +2.4 degF |
| Tavg, CMIP5 | +2.7 degF | +2.6 degF | +2.8 degF | +2.8 degF |
| **2070s** | | | | |
| Prcp, CMIP3 | +5.2 % | +5.0 % | +5.1 % | +6.4 % |
| Prcp, CMIP5 | +6.1 % | +6.3 % | +5.3 % | +5.7 % |
| Tavg, CMIP3 | +4.2 degF | +4.1 degF | +4.3 degF | +4.4 degF |
| Tavg, CMIP5 | +4.5 degF | +4.4 degF | +4.7 degF | +4.7 degF |

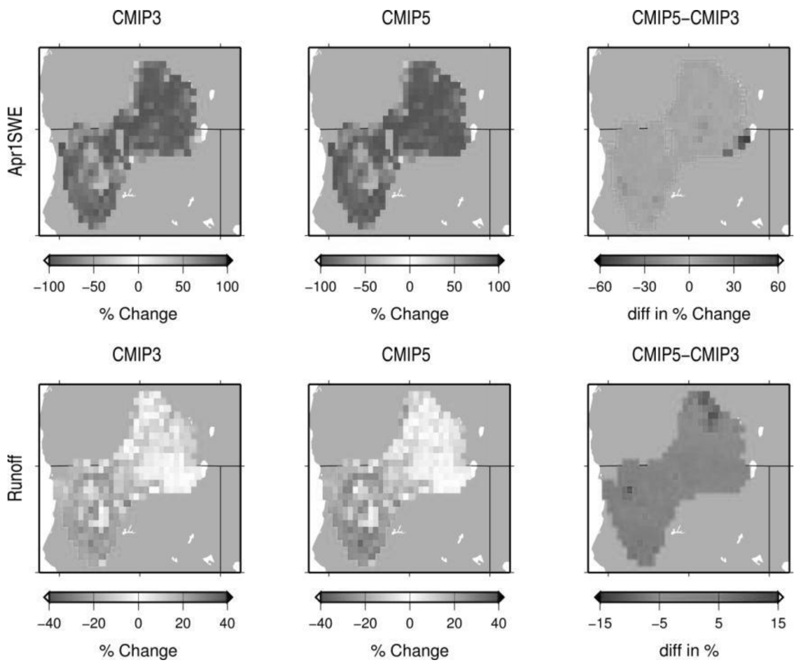
### 3.6.2 Water Balance

Comparisons of CMIP3 and CMIP5 projections of April 1 SWE and mean annual runoff, both calculated using the VIC model, are illustrated in Figure 3-27 for the 2030s and Figure 3-28 for the 2070s and summarized in Table 3-6. Projections of snowpack on April 1 are presented, in part, because this is a common measure often used in climate change impact studies across the western U.S., but also because historical snowpack is at, or just past, its peak in early April and this measure is often used by water managers as a measure of spring and summer water supply. For the 2070s, CMIP3- and CMIP5-based projections of April 1 SWE show a similar magnitude of change and slight spatial differences (refer to Figure 3-28, upper left and upper central panels). The water balance terms are influenced by changes in precipitation and temperature across the landscape. Although both CMIP3 and CMIP5 projections indicate declines in April 1 SWE by roughly 30 to 40 percent by the 2030s and 60 percent by the 2070s for the central tendency, despite projected increases in annual runoff (see Table 3-5 for computed percent change over the basin and three dominant climate divisions).




Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

**Figure 3-27. Comparison of percent change (2030s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios based on CMIP3 and CMIP5**




Notes: The right-hand column illustrates the difference between the first two columns, i.e., between CMIP5 projections and CMIP3 projections.

**Figure 3-28. Comparison of percent change (2070s to historical) in mean April 1 SWE and mean annual runoff for central tendency HDe scenarios, based on CMIP3 and CMIP5**

For both future time horizons, greater decreases in snowpack are projected for lower elevation regions while mountainous parts of the basin, namely the Cascades and Trinity Alps, show smaller projected decreases in April 1 SWE. Further, for the VIC model pixel that contains Mount Shasta (refer to the white square in the central area of the upper left and upper central panels of Figure 3-27 and Figure 3-28), snowpack is not projected to change substantially, likely due to the combined effects of its relatively high elevation, projected increases in precipitation, and projected increases in temperature.

The upper right panels of Figure 3-27 and Figure 3-28 show the differences in April 1 SWE between CMIP3 and CMIP5 projections. Although differences for the 2030s and 2070s central tendency are small, the CMIP3 projection indicates a larger decrease in snowpack than CMIP5 in parts of the Upper Klamath Basin for the 2030s and the easternmost portion of the basin in California for the 2070s. Smaller differences in April 1 SWE are projected for the 2070s. Mean percent

change in April 1 SWE across the Klamath River Basin is -33.8 percent for the 2030s and -58.2 percent for the 2070s.

**Table 3-6. Summary of projected changes in April 1 SWE and annual runoff for the 2030s compared with the historical baseline (1950-1999) for the Klamath River Basin (basin-wide) and the watershed's three dominant climate divisions**

| Climate Division | Basinwide | High Plateau | South Central | North Coast Drainage |
|---|---|---|---|---|
| **2030s** | | | | |
| **Apr1 SWE, CMIP3** | -33.8 % | -38.9 % | -31.0 % | -32.5 % |
| **Apr1 SWE, CMIP5** | -39.8 % | -41.4 % | -35.4 % | -39.8 % |
| **Ann Runoff, CMIP3** | +7.3 % | +1.4 % | -0.6 % | +8.8% |
| **Ann Runoff, CMIP5** | +11.6% | +3.4 % | +4.6 % | +12.9 % |
| **2070s** | | | | |
| **Apr1 SWE, CMIP3** | -58.2 % | -61.9 % | -54.7 % | -57.3 % |
| **Apr1 SWE, CMIP5** | -62.0 % | -65.6 % | -58.8 % | -61.1 % |
| **Ann Runoff, CMIP3** | +13.9 % | +0.1 % | -0.5 % | +16.4 % |
| **Ann Runoff, CMIP5** | +15.3 % | -5.1 % | -2.5 % | +18.7 % |

According to projections based on both CMIP3 and CMIP5 for the 2030s and 2070s, mean annual runoff is projected to increase in the Lower Klamath Basin while changes in the Upper Klamath Basin vary both in magnitude and direction and between CMIP3 and CMIP5 (refer to lower panels of Figure 3-27 and Figure 3-28). Projected changes in runoff based on climate division show increases in the North Coast Drainage on the order of 16 or 19 percent (for CMIP3 and CMIP5, respectively) for the 2070s central tendency and decreases across the South Central climate division on the order of 1 to 3 percent (for CMIP3 and CMIP5, respectively). Across the High Plateau (the region upstream and to the east of Upper Klamath Lake; refer to Figure 3-2), projections are mixed, with CMIP3-based projections indicating a slight increase in mean annual runoff and CMIP5-based projections indicating a decrease in mean annual runoff for the 2070s. The lower right panels of Figure 3-27 and Figure 3-28 illustrate the spatial difference between CMIP3 and CMIP5 for the 2030s and 2070s, respectively. For the 2030s, CMIP5 projections indicate greater changes in runoff over the mainstem Klamath River area than CMIP3, yet smaller changes in runoff over the higher elevation regions of the Trinity River basin and Tule Lake area. For the 2070s, CMIP5 projects lower runoff change than

## CMIP3 and CMIP5 Comparison – Water Balance

CMIP3 and CMIP5 water balance projections are largely consistent, indicating decreases in April 1 SWE on the order of 34-40 percent for the 2030s and close to 60 percent for the 2070s, and increases in annual runoff of 7-12 percent for the 2030s and 14-15 percent for the 2070s.

CMIP3 in the Upper Klamath Basin and lower runoff change than CMIP3 in the Lower Klamath Basin.

The differences between CMIP3 and CMIP5 projections for the 2070s central tendency in projected precipitation, temperature, snowpack, and runoff show great similarities in the central tendency scenario for the Klamath River Basin as a whole. However, there are notable differences in that CMIP5 projections tend to be wetter and warmer over the Klamath River Basin than those from CMIP3. Also, there are notable spatial differences that are important to consider when relying on projections from either CMIP3 or CMIP5 (but not both) for water management decision-making.

## 3.7 Future Availability

Projected availability of surface water and groundwater in the Klamath River Basin was assessed by evaluating changes in seasonal precipitation and temperature, snowpack, timing and quantity of runoff, soil moisture and ET, low flow frequency, and groundwater recharge and discharge. For the most part, this assessment focuses on projections based on CMIP5; however, corresponding results based on CMIP3 projections were also developed and are included in Appendix B, Supplemental Information for Assessment of Water Supply.

Figure 3-29 illustrates projections of seasonal basin mean precipitation for the 2070s compared with the historical period, based on CMIP5. Each panel includes box plots of historical and projected precipitation, where the boxes represent the 25th, 50th, and 75th percentile values for seasonal precipitation averaged across the Klamath River Basin, and the whiskers represent the 5th and 95th percentile values.

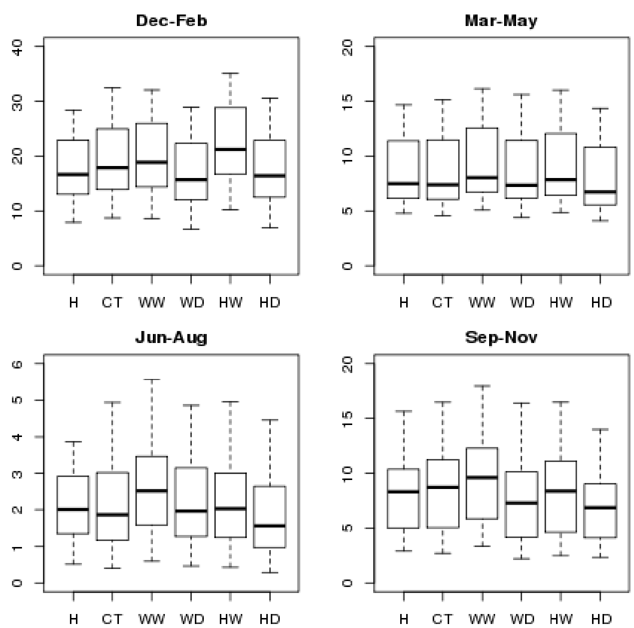
**Future Availability – Precipitation and Temperature**

Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.

In general, the box plots show that the majority of precipitation falls between December and February, an order of magnitude greater than between June and August. In winter (December through February; refer to upper left panel of Figure 3-33), central tendency, WW, and HW scenarios indicate an increase in precipitation, while the WD and HD scenarios indicate decreases in precipitation over this time period. The range between 5th and 95th percentile values across each of the five HDe climate change scenarios appears similar. Projections for the spring period between March and May (upper right panel) and the autumn period between September and November (lower right panel) appear similar to historical conditions, with slight increases for the wetter scenarios (WW and HW) and slight decreases for the drier scenarios (WD and HD). Projections for the summer period (June through August; refer to lower

left panel) show a slight decrease in the median of the central tendency scenarios compared with historical, and decreases in general for the drier scenarios and increases for the wetter scenarios. However, it is notable that the WW scenario indicates a larger increase in summer precipitation than the HW scenario.

It is important to mention that HDe climate change scenarios were developed based on projected changes from multiple GCMs in annual precipitation and temperature across the basin, potentially dampening the signal toward drier summers and wetter winters (as shown in Figure 3-19). Also, the Klamath River Basin water supply assessment does not evaluate projected changes in extreme precipitation events, which are also likely to change as a result of climate change. The focus of this water supply assessment is on the watershed's overall monthly to seasonal water balance, rather than the effects of individual storm events.



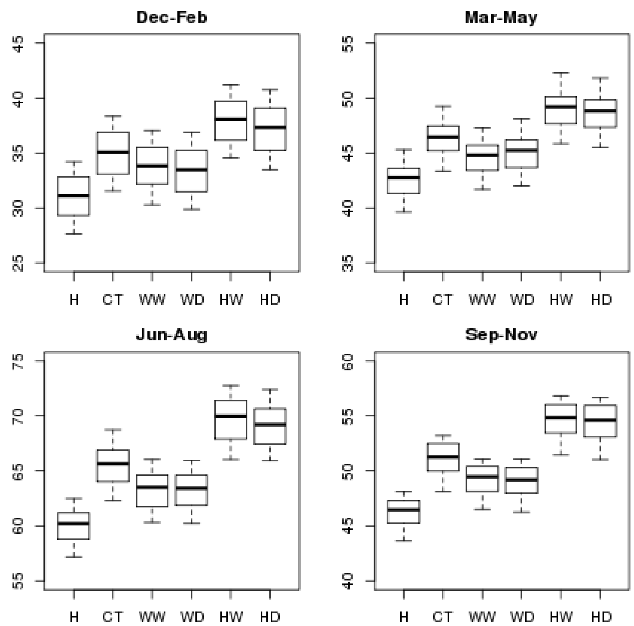

Notes:

1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

**Figure 3-29. Seasonal basin mean precipitation (in inches), CMIP5 2070s and historical (1950–1999)**

Projections of seasonal temperatures for the 2070s, compared with the historical period (1950–1999) show similar patterns in HDe climate change scenarios across

seasons (refer to Figure 3-30). The hotter HDe scenarios (HW and HD) indicate warmer temperatures relative to the warmer HDe scenarios (WW and WD), compared with historical temperatures. Central tendency scenarios tend to fall in between the warmer and hotter scenarios. What is notable about the seasonal temperature projections is that, for all seasons, the hotter HDe scenarios are mostly outside the range of corresponding historical seasonal temperatures. In summer and fall, even the central tendency HDe scenarios are mostly outside the range of historical temperatures.

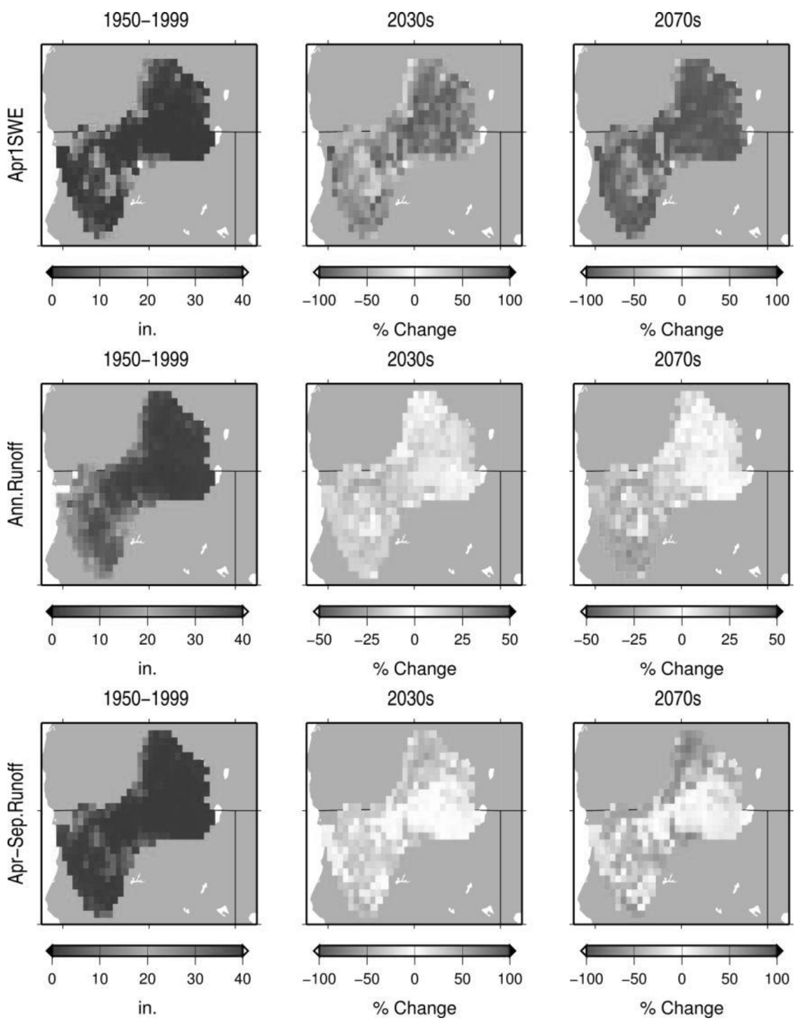



Notes:
1. Heavy black line represents the median of 50 seasonal basin mean values (one for each year), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD=– hot dry.

**Figure 3-30. Seasonal basin mean daily average temperature (in degrees F), CMIP5 2070s and historical (1950–1999)**

### 3.7.1 Changes in Water Balance Terms

This section summarizes projected spatial and basin mean changes in snowpack, annual and spring runoff, soil moisture, and actual ET for the two future time horizons (2030s and 2070s), based on central tendency CMIP5 projections. Figures corresponding to those shown in this section based on CMIP3 projections are included in Appendix B, Supplemental Information for Assessment of Water Supply. It should be noted that paleo-conditioned streamflow projections were not incorporated into the analysis of climate change impacts on surface water balance variables. Figures 3-31 and 3-32 are similar in format in that the left column illustrates mean historical conditions over the period 1950–1999. The middle column illustrates projected percent change for the 2030s future time horizon compared with historical, while the right column illustrates projected percent change for the 2070s future time horizon compared with historical.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from historical values to the 2030s and 2070s, respectively.

**Figure 3-31. Comparison of percent change in mean April 1 SWE, mean annual runoff, and mean April-September runoff for the central tendency HDe scenarios based on CMIP5**

Mean historical SWE on April 1 (Figure 3-31, top row) falls within the range of little or no snow in the coastal region to almost 40 inches of SWE in the Cascade

Mountains (and even greater snowpack at Mount Shasta). Based on CMIP5 projections, mean percent change in April 1 SWE across the Klamath River Basin is -40 percent for the 2030s and -62percent for the 2070s. Greater decreases are projected for middle to lower elevation parts of the basin. Snowpack at Mount Shasta is expected to exhibit little change (on a percent basis) by the 2030s or 2070s.

Historical mean annual runoff over the 1950–1999 period ranges from a little less than 1 inch in the northeastern part of the basin to more than 40 inches in parts of the coastal region and near Mount Shasta. Basin-wide mean percent change in annual runoff is +12 percent for the 2030s and +15 percent for the 2070s. Most of the Lower Klamath Basin is projected to experience increases in mean annual runoff, while the Cascades region is projected to experience decreases. What is notable with respect to projected changes in mean annual runoff in the Upper Klamath Basin is that projected increases in runoff appear greater for the 2030s than the 2070s. This is likely due to the combined effects of projected increases in precipitation along with projected increases in temperature. For the 2030s, increased precipitation dominates the water balance, resulting in larger increases in annual runoff, while for the 2070s corresponding increases in temperature may cause actual ET to be great enough to show an overall smaller increase in mean annual runoff than for the 2030s.

### Future Availability – Water Balance

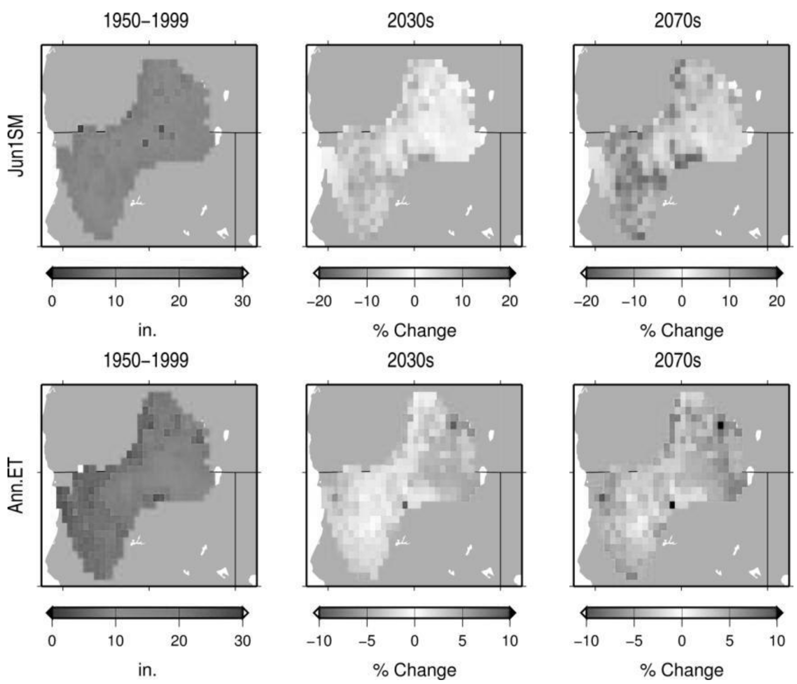
Mean percent change based on CMIP5 central tendency projections includes:

- April 1 SWE: -40 percent (2030s) and -62 percent (2070s)
- Spring (April–September) runoff: -25 percent (2030s) and -40 percent (2070s)
- June 1 soil moisture: -4.9 percent (2030s) and -8.7 percent (2070s)
- Annual ET: +2.6 percent (2030s) and +4.1 percent (2070s)

Historical irrigation season (April through September) runoff over the 1950–1999 period ranges from less than 1 inch to about 30 inches, with higher spring runoff occurring in the mountainous parts of the Klamath River Basin. Mean percent change in spring (April through September) runoff is -25 percent for the 2030s and -40 percent for the 2070s.

Similar to evaluating snowpack at its general peak, projections of soil moisture on June 1 are presented because, in the absence of irrigation or other water management, June is the month of greatest soil moisture throughout the Klamath River Basin. Changes in maximum soil moisture may be of interest to water managers in terms of understanding projected changes in groundwater and soil water availability. Mean historical soil moisture on June 1 over the period 1950–

1999 ranges from less than 1 inch to almost 30 inches, with the greatest soil moisture occurring in mountainous regions with melting snowpack and generally higher precipitation (Figure 3-32). Mean percent change in June 1 soil moisture across the Klamath River Basin is a reduction by 4.9 percent for the 2030s and a reduction by 8.7 percent for the 2070s, compared with the historical period. The pattern of projected change in June 1 soil moisture is similar to that of spring runoff, indicating that projected reductions in soil moisture correspond with reductions in spring runoff. Interestingly, these reductions also correspond with projected increases in mean annual runoff, indicating that there may be a seasonal shift in runoff (discussed in the next section), and therefore June 1 soil moisture.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate percent change from 1990s values to the 2030s and 2070s, respectively.

**Figure 3-32. Comparison of percent change in mean June 1 soil moisture and mean annual evapotranspiration for the central tendency climate scenario, using groupings of GCMs from CMIP5**

Mean historical annual ET over the period 1950–1999 ranges from less than 10 inches to about 33 inches (Figure 3-32). Higher ET values tend to occur in regions with greater water availability (i.e., greater precipitation), like in the Lower Klamath Basin and other mountainous regions. Mean percent change in annual ET basin wide is +2.6 percent for the 2030s and +4.1 percent for the

2070s. Larger percentage increases in ET appear to be projected for parts of the Upper Klamath Basin. However, these results may not reflect relative increases in the amount of water lost to ET, due to the fact that the Upper Klamath Basin generally has lower annual ET.

Figure B-12 in Appendix B, Supplemental Information for Assessment of Water Supply, illustrates projected changes in June 1 soil moisture and mean annual ET for the 2030s and 2070s central tendency, based on the CMIP3 HDe scenarios. Results are similar in spatial patterns of projected change; however, CMIP3-based projections generally indicate smaller projected changes in June 1 soil moisture and annual ET than CMIP5.

### 3.7.2 Changes in Timing and Quantity of Runoff

This section evaluates projected changes in mean monthly streamflow at selected locations within the Klamath River Basin, the projected shift in timing of mean monthly hydrographs for one example location within the basin, and low flow frequency statistics for select locations. Analyses focus on projected changes for the two future time horizons (2030s and 2070s) based on CMIP5 projections. Figures similar to those presented in this section, but based on CMIP3 projections, are provided in Appendix B, Supplemental Information for Assessment of Water Supply. However, the presentation of projected streamflow results at Keno, Oregon (Figure 3-33) includes projections based on both CMIP3 and CMIP5 to allow for direct comparison of mean monthly hydrographs under various types of projections.

Simulated historical and projected mean monthly hydrographs for the Klamath River at Keno, Oregon are presented in Figure 3-33 to illustrate an example of projected changes in overall flow volume and seasonal peak timing of streamflow in the watershed. The top two panels summarize projections based on CMIP3 projections, while the bottom two panels summarize projections based on CMIP5 projections. The mean monthly historical hydrograph is identical in each panel and was computed over water years 1950–1999 (i.e., September 1949–October 1999).

Both CMIP3- and CMIP5-based projections indicate a decrease in spring and summer streamflow for the 2030s and a greater decrease by the 2070s. The wetter of the five HDe climate change scenarios (HW and WW) indicate greater streamflow volume overall, along with higher seasonal peaks. Drier scenarios (HD and WD) indicate reduced streamflow volumes and reduced peaks. Projections for the 2030s (based both on CMIP3 and CMIP5) indicate a shift in seasonal peak timing from approximately zero to one month earlier (a shift from April to March). For the 2070s, projected shifts in seasonal peak timing are zero to two months earlier (a shift from April to as early as February).

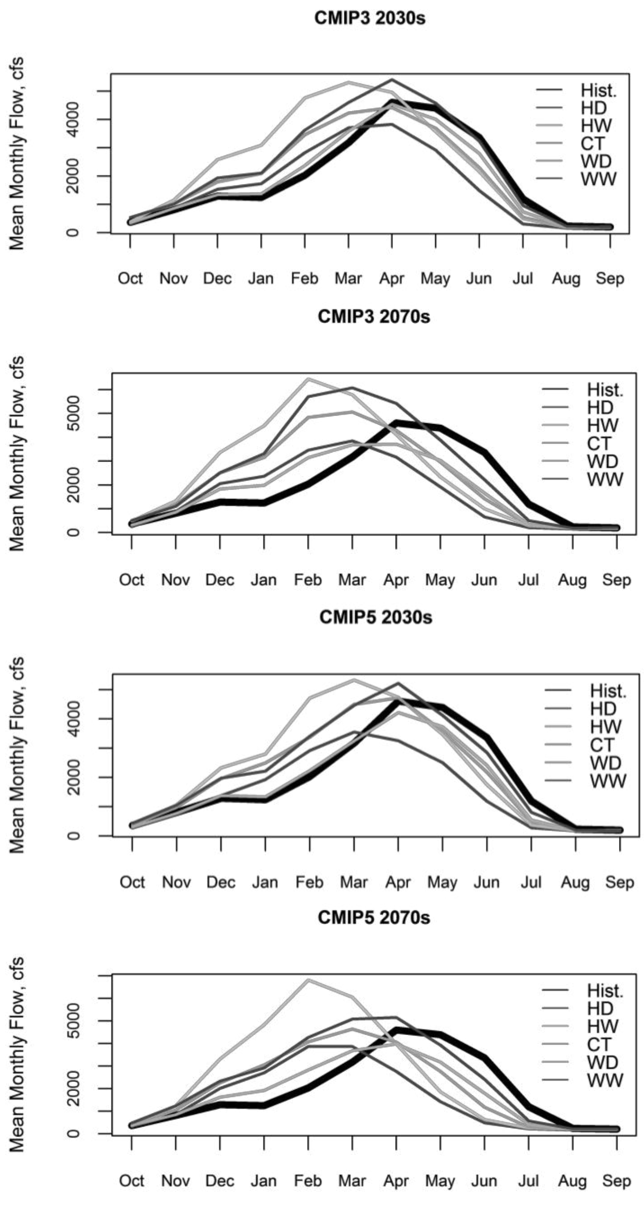



**Figure 3-33. Historical and projected mean monthly hydrographs for Klamath River at Keno, OR (USGS ID 11509500)**

The projected shifts in streamflow volume and timing for Keno, Oregon are typical of those sub-basins within the Klamath River Basin that are influenced in part by snowmelt. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume. Wetter scenarios indicate greater increases, while drier scenarios indicate anywhere from a slight decrease in flow volume to a slight increase in flow volume (figures not shown).

The seasonality of streamflow, in particular low flow periods, is of interest to water managers since there is often limited supply for numerous competing resources during low flow periods. At the same time, natural streamflow variability, including low flows, serves an important function for a river ecosystem. Richter et al. (1997) discuss an approach for setting streamflow-based targets for ecosystem management. The approach is based on the notion that streamflow characteristics are useful indicators for assessing ecosystem integrity over time. One of the identified indicators is the annual 7 day minimum of flow. As part of the assessment of future water supply, we evaluated projected changes in the 7Q10 low flow frequency statistic. This statistic is defined as the lowest 7 day mean flow at a location, occurring at a 10 year recurrence interval. As one example of its application, this statistic is used to define the “critical condition” for adverse impact on aquatic biota in Washington state (Chapter 173-201A of the Washington Administrative Code). As part of this assessment, the 7Q10 low flow frequency statistic is evaluated for a number of sites throughout the Klamath River Basin.

Projected changes in the 7Q10 low flow frequency statistic were evaluated as part of the Klamath River Basin water supply assessment as a way of focusing on changes in streamflow during their seasonal low periods. Low flow periods typically occur in late summer when precipitation is low, stored water supplies have largely been consumed, and anadromous fish species begin their upstream migration to spawning grounds.

Table 3-7 summarizes projected changes in 7Q10 low flow frequency for eight selected sites throughout the Klamath River Basin. Primary projected values in the table represent the central tendency, while the values in parenthesis represent the range of the five HDe climate change scenarios for CMIP3 and CMIP5 for each future time horizon. Projected changes were computed as a ratio between the projected value and the historical value. Values greater than one indicate an increase in the 7Q10 low flow, while values less than one indicate a decrease in the 7Q10 low flow (these are shown in bold in the table).

**Table 3-7. Summary of ratios between projected and historical 7Q10 low flow frequency statistics for various sites within the Klamath River Basin**

| Site ID | Site Name | Hist. 7Q10 (cfs) | 2030s CMIP3 | 2030s CMIP5 | 2070s CMIP3 | 2070s CMIP5 |
|---|---|---|---|---|---|---|
| 00020 | Sprague R near Chiloquin | 68.6 | 1.03 (**0.943**-1.06) | 1.00 (**0.955**-1.05) | 1.01 (**0.917**-1.07) | 1.01 (**0.927**-1.07) |
| 00026 | Klamath R blw Iron Gate Dam | 167 | **0.989** (**0.965**-1.01) | **0.989** (**0.970**-1.01) | **0.994** (**0.949**-1.01) | **0.995** (**0.952**-1.01) |
| 00004 | Klamath R at Orleans | 313 | **0.998** (**0.980**-1.01) | **0.995** (**0.982**-1.01) | **0.996** (**0.969**-1.01) | **0.994** (**0.977**-1.01) |
| 00029 | Klamath R near Klamath | 443 | 1.00 (**0.983**-1.00) | **0.997** (**0.989**-1.00) | **0.998** (**0.977**-1.00) | **0.996** (**0.981**-1.00) |
| 00022 | Salmon R at Somes Bar | 23.4 | **0.966** (**0.932**-1.01) | **0.979** (**0.957-0.966**) | **0.949** (**0.940-0.996**) | **0.983** (**0.953-0.987**) |
| 00031 | Shasta R near Yreka | 29.2 | 1.01 (**0.990**-1.01) | 1.01 (**0.979**-1.01) | 1.02 (**0.990**-1.02) | 1.02 (**0.979**-1.02) |
| 00032 | Scott R near Ft Jones | 25.9 | 1.02 (1.01-1.04) | 1.04 (1.01-1.05) | **0.996** (**0.996**-1.03) | 1.07 (**0.981**-1.07) |
| 00034 | Trinity R at Hoopa | 99.4 | 1.01 (1.00-1.01) | 1.01 (1.00-1.02) | 1.02 (1.00-1.02) | 1.01 (1.01-1.02) |

Note: Primary values represent the central tendency HDe scenario. Values in parenthesis represent the range of the five HDe climate change scenarios. Values above 1 indicate an increase. Values less than 1 indicate a decrease (shown in bold).

Select sites on the Sprague, Shasta, Scott, and Trinity Rivers are projected to experience increases in 7Q10 low flows for the 2030s and 2070s central tendency, compared with the historical period; however, projections range from slight decreases to slight increases. Projected increases are largely due to projected increases in precipitation. The Trinity River site (00034) is the only site evaluated where the entire range of projections indicate an increase in the 7Q10 low flow statistic. Select sites including three on the mainstem Klamath River (below Iron Gate Dam, at Orleans, and near Klamath) and one on the Salmon River are projected to experience decreases in the 7Q10 low flow central tendency, compared with the historical baseline; however, projections range from slight decreases to slight increases. The Salmon River site (00022) is the only one evaluated where the entire range (except for the 2030s CMIP3) indicates a decrease in the 7Q10 low flow statistic. Projected decreases are likely due to the combined effects of increased precipitation, increased temperature,

## Future Availability – Runoff Quantity and Timing

For those basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For those sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.

and increased ET. It should be noted that projections based on CMIP3 and CMIP5 show similar results in their central tendency.

Projections shown in Table 3-7 are based on streamflow generated by the VIC hydrologic model which represents natural flow, absent of management effects such as withdrawals and groundwater pumping. Combined effects of changes due to climate change and changes in management practices may alleviate or exacerbate projected changes in low flows in the Klamath River Basin. It should be stressed that the historical values presented in Table 3-7 are lower than those typically experienced in the watershed. These values are based on the lowest 7-day running mean that has a 1:10 chance of occurrence. Such an occurrence would likely occur in a prolonged drought condition where groundwater levels (which would typically provide supplemental baseflow) are also negatively impacted. In addition, it should be noted that the VIC model does not represent complex surface and groundwater interactions and therefore may not generate realistic baseflow in a heavily groundwater influenced watershed such as the Klamath River Basin. Additional discussion related to VIC model limitations is provided in Appendix B, Supplemental Information for Assessment of Water Supply.

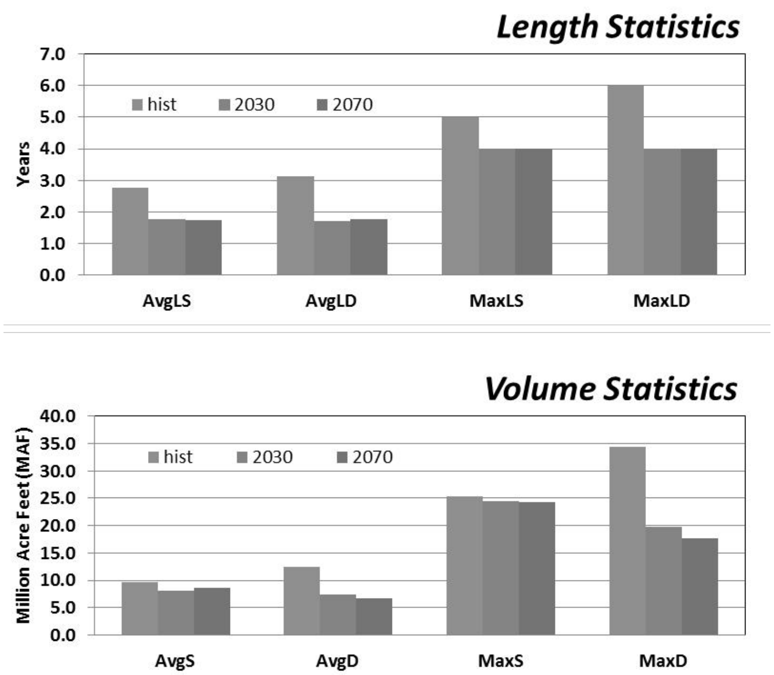
### 3.7.3 Changes in Drought and Surplus based on Paleo Conditioned Streamflow Projections

Using the approach described in Section 3.5.1.3, Deriving Paleo-Conditioned Streamflow Projections, drought and surplus statistics were analyzed for all HDe scenarios to characterize projected changes in droughts and surpluses. Drought and surplus statistics may be generated at any streamflow location in the Klamath River Basin using this approach. For the Klamath River Basin water supply assessment, we focus on results at the Klamath River near Klamath, California, which represents the integrated response to drought and surplus throughout the basin since it is close to the mouth of the river. Results are summarized graphically for the 2030s and 2070s for CMIP5-based central tendency scenarios in Figure 3-34. The data behind the figure, in addition to other HDe climate change scenarios, is summarized by Tables B-1 and B-2 in Appendix B, Supplemental Information for Assessment of Water Supply.

> **Future Availability – Droughts and Wet Periods**
>
> Analyses of surplus and drought statistics based on the paleo record are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes.

Overall, the surplus and drought statistics are similar for the 2030 and 2070 periods. Maximum lengths of drought are expected to decline along with a reduction in maximum deficit volumes. Similar conclusions can be drawn for the average drought lengths and deficit volumes. The projections correspond

with projections of increased precipitation overall in the Klamath River Basin for both future time horizons (2030s and 2070s). In spite of these statistics pointing to wetter conditions, the maximum surplus volumes are estimated to be nearly equal to the historical maximum surplus. The paleo-hydrologic analysis provides a way to superimpose variability by altering sequences, and for water systems the sequence in which wet and dry spells occur is critical.




Note: AvgLS and AvgLD: average length of surplus and drought, respectively. MaxLS and MaxLD: maximum length of surplus and drought, respectively. AvgS and AvgD: average surplus and drought, respectively MaxS and MaxD: maximum length of surplus and drought, respectively.

**Figure 3-34. Surplus and drought statistics for the paleo-conditioned CMIP-5 central tendency climate scenario**

### 3.7.4 Changes in Groundwater Supply

The impacts of climate change on groundwater supplies were evaluated for three primary groundwater basins within the Klamath River Basin: the Upper Klamath Basin (upstream of Iron Gate Dam) and the Scott and Shasta Valleys. Similar to the assessment of surface water supplies, this assessment focuses on results based on CMIP5 projections. Figures similar to those presented below but based on

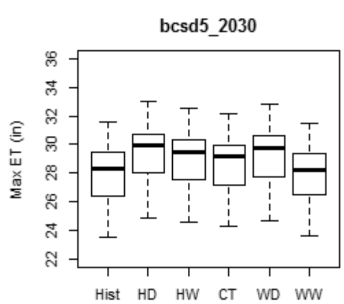
CMIP3 projections are provided in Appendix B, Supplemental Information for Assessment of Water Supply. This assessment also focuses on groundwater impacts as a result of projected changes in climate and surface water hydrology (as well as population for the Scott and Shasta Valleys) and does not consider changes in pumping or other changes in water management.

#### *3.7.4.1 Upper Klamath Basin*

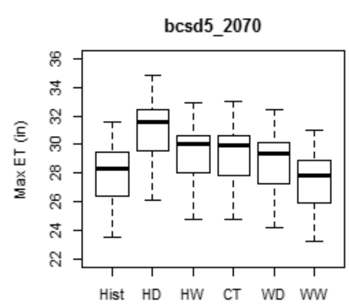
The following analysis of climate change impacts focuses first on the perturbed inputs of maximum ET and mean annual recharge for the projected MODFLOW simulations, and then on MODFLOW simulation results including projected changes in groundwater elevations and discharge to surface water.

**Inputs**

Projections for the three perturbed MODFLOW input terms are first discussed to provide context for the discussion of projected changes in groundwater elevations and discharge. Figure 3-35 shows historical and projected mean maximum ET (as defined in the approach) for the five HDe climate change scenarios on an annual basis. As described in the approach, projected maximum ET values were computed based on annual change factors applied to historical maximum ET. The figure shows that mean annual maximum ET is projected to increase for the 2030s and 2070s, compared with the historical period, when looking at corresponding percentile levels. For the 2030s, the drier scenarios (HD and WD) appear to have slightly larger increases than the wetter scenarios. For the 2070s, the HD scenario indicates a larger increase in maximum ET than all other scenarios.




a)




b)

Notes:

1. The heavy black line represents median of values across the 47 VIC cells within the Upper Klamath Basin MODFLOW model domain that contains evapotranspiration cells (defined by Gannett et al. [2012] Figure 4), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

**Figure 3-35. Summary of projected mean annual maximum ET for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years**

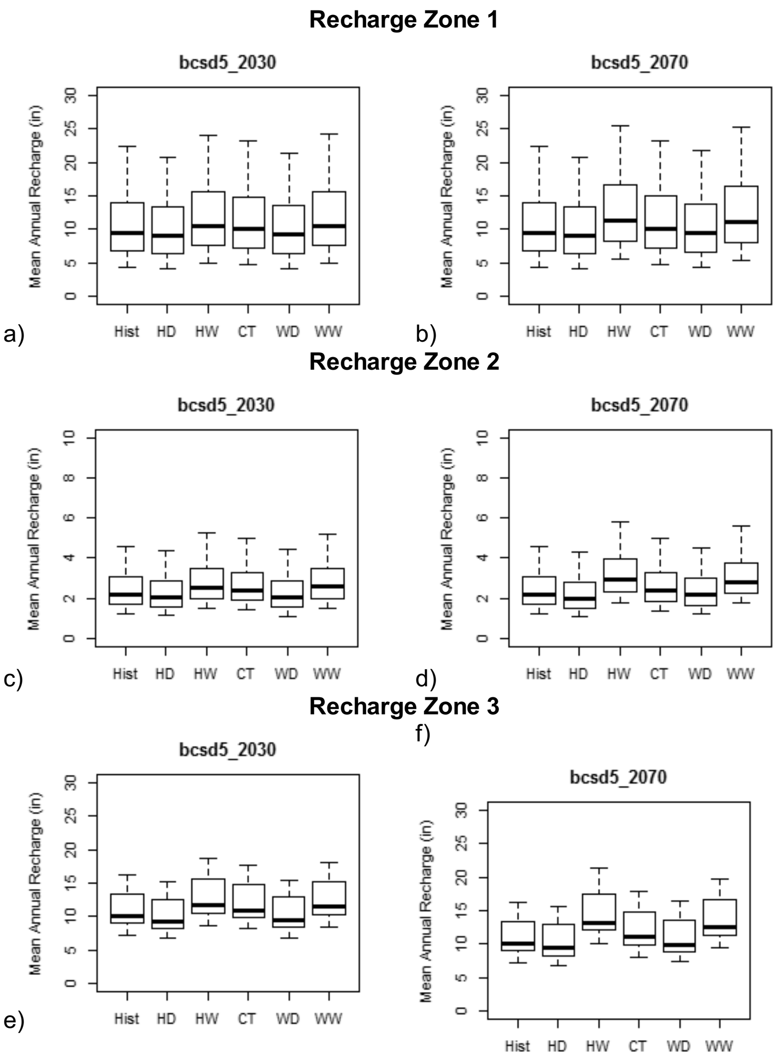
Table 3-8 summarizes the projected increases in the central tendency of mean annual maximum ET for the 2030s and 2070s, for projections based both on CMIP3 and CMIP5. Results show greater increases in maximum ET for projections based on CMIP3 than those based on CMIP5.

**Table 3-8. Summary of central tendency projections of maximum ET for the 2030s and 2070s, compared with the historical baseline (1970–1999).**

| Central Tendency Projections | 2030s | 2070s |
|---|---|---|
| CMIP3 | +4.5% | +7.1% |
| CMIP5 | +3.3% | +5.7% |

Projected recharge was input into future simulations of the Upper Klamath Basin MODFLOW model for five HDe climate change scenarios (for two future time periods and both CMIP3 and CMIP5), based on unique historical precipitation-recharge relationships by recharge zone. Figure 3-36 illustrates box plots of projected mean annual recharge by zone based on CMIP5 projections (refer to Figure 3-10 for identification of recharge zones). In general, projections of recharge are similar between future time horizons, both in magnitude and when considering the relative change across different climate change scenarios. Recharge zone 1 has a greater range of recharge (as evidenced by the difference between 5th and 95th percentile values) than zones 2 or 3. Also, recharge zone 2 has substantially lower recharge than the other zones, including the historical values. Lower recharge in zone 2 likely corresponds with less precipitation and snowpack to help drive recharge. Projected changes in mean annual recharge for zone 1 range from increases to small decreases. Wetter scenarios generally indicate increases in recharge, while drier scenarios generally indicate decreases, particularly looking at the median ($50^{th}$ percentile) change.

Table 3-8 summarizes mean annual recharge by zone, and basin-wide, for the central tendency (2030s and 2070s, CMIP3 and CMIP5). For the 2030s, projected changes in recharge differ substantially between CMIP3- and CMIP5-based scenarios. However, by the 2070s CMIP3- and CMIP5-based scenarios are more similar. In fact, the difference in projected recharge change for zone 1 is almost as great between CMIP3 and CMIP5 for the 2030s as the difference between the 2030s and 2070s based on CMIP3. These results were verified; however, it illustrates how closely recharge projections correspond with projections of future precipitation. Basin-wide precipitation changes for the central tendency are projected to be about +2.4 percent (based on CMIP3) and +4.1 percent (based on CMIP5) for the 2030s and about +5.2 percent (based on CMIP3) and +6.1 percent (based on CMIP5) for the 2070s. Projections of recharge for other HDe climate change scenarios show similar correspondence with precipitation projections.




Notes:

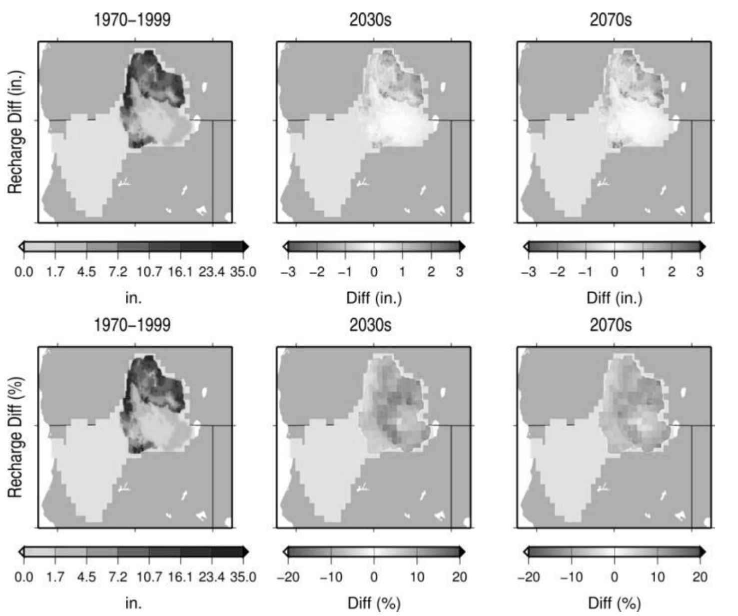
1. Heavy black line represents median of values across the 62 VIC cells within the MODFLOW model domain that are within recharge zone 1, while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW = hot wet, HD = hot dry.

**Figure 3-36. Summary of projected mean annual recharge for MODFLOW model recharge zone 1 for two future time horizons (2030s and 2070s) compared with the historical baseline period of 1970–1999 water years**

**Table 3-9. Summary of central tendency projected change in mean annual recharge by zone for the 2030s and 2070s, compared with the historical baseline (1970–1999 water years)**

| Central Tendency Projections | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| **Recharge Zone 1** | +3.0% | +6.1% | +7.9% | +6.5% |
| **Recharge Zone 2** | +4.3% | +8.9% | +8.0% | +9.4% |
| **Recharge Zone 3** | +4.6% | +8.8% | +10.5% | +10.0% |
| **Basin Wide** | +3.4% | +8.4% | +8.8% | +8.2% |

Figure 3-37 spatially illustrates historical and projected change in mean recharge for CMIP5-based central tendency scenarios (2030s and 2070s) based on data used as input by the MODFLOW model for the Upper Klamath Basin. The left column contains identical panels (top row and bottom row) showing the historical seasonal mean recharge (in inches) used in the calibrated model (similar to Figure 3-10). The middle and right columns contain projected change for the 2030s and 2070s, respectively (top row in inches, bottom row in percent change).




Note: The left-hand column illustrates the historical values (top row and bottom row are identical), while the middle and right-hand columns illustrate change (top row in inches, bottom row in percent change) from 1970-1999 values to the 2030s and 2070s, respectively.

**Figure 3-37. Comparison of change in mean annual recharge to groundwater for the central tendency climate scenarios, using groupings of GCMs from CMIP5**

### Outputs

The Upper Klamath Basin MODFLOW model was implemented using projected inputs as previously described. For the purpose of the Klamath River Basin water supply assessment, historical pumping was used to explore the effects of climate change alone on the groundwater balance.

The MODFLOW model computes an overall groundwater budget on a seasonal timestep. Table 3-10 summarizes projected mean changes in the primary output components of the budget for the central tendency HDe scenario. These components consist of groundwater discharge to drains, evapotranspiration, and groundwater discharge to streams. Drains include surface water conveyances such as constructed canals and ditches and natural springs. Units for discharge to drains may be described as cubic feet per second (cfs) per grid cell, where discharge (in cfs) is the mean computed over the simulation period (water years 1970–1999) and across all MODFLOW grid cells designated as drains. Basin-wide changes in groundwater discharge to drains are projected to increase by less than two percent for both the 2030s and 2070s. Considering four central tendency scenarios (CMIP3 2030s and 2070s as well as CMIP5 2030s and 2070s), the greatest increase in discharge to drains is projected for the CMIP5-based 2030s scenario. The integration of projected changes in temperature and precipitation in the modeled domain (i.e., the Upper Klamath Basin) indicate greater increases for the 2030s than for the 2070s based on CMIP5.

Units for ET are inches, where ET is the mean computed over the simulation period and across all MODFLOW grid cells designated as having ET. Projected changes in mean ET indicate increases according to all central tendency projections (Table 3-10), with greater increases projected for the 2070s than for the 2030s. ET corresponds more closely with temperature than with precipitation. Projections of annual temperature (Table 3-5) indicate similar projected increases in the central tendency for the 2030s (CMIP3 and CMIP5) and similar yet greater increases for the 2070s.

Discharge to streams is presented in units similar to discharge to drains, namely mean discharge (cfs) per MODFLOW grid cell designated as stream. Seasonal mean discharge to streams is projected to increase, with the greatest increases projected for the CMIP5 2030s and the CMIP3 2070s scenarios (Table 3-10).

**Table 3-10. Average percent change in mean groundwater balance variables**

| Central Tendency Projections | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| GW Losses to Drains | +0.4% | +1.8% | +1.2% | +1.3% |
| GW Losses to ET | +4.1% | +5.2% | +7.3% | +6.4% |
| GW Losses to Streams | +2.0% | +5.2% | +5.3% | +4.8% |

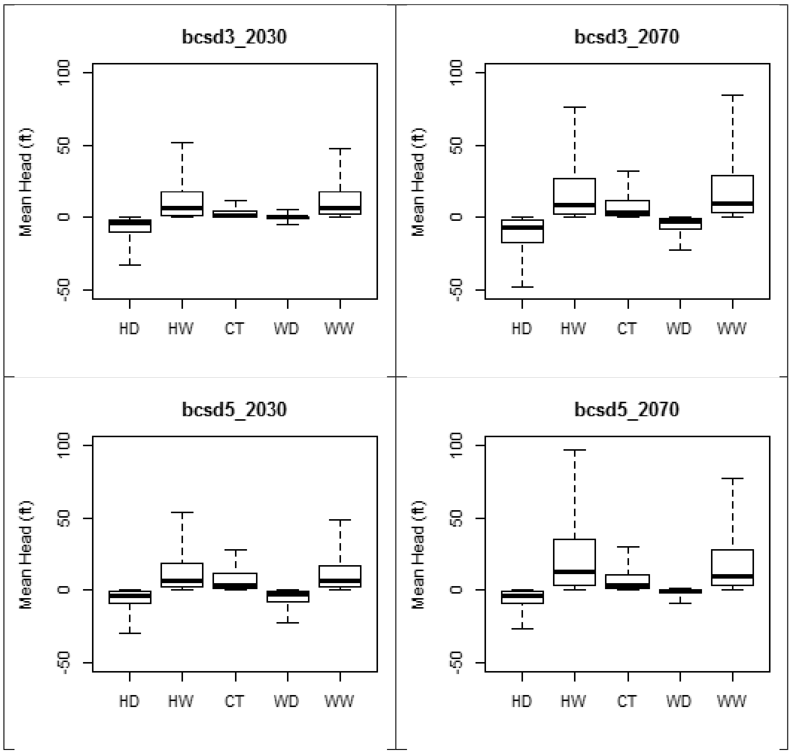
In addition to projected changes in the overall groundwater budget, projected changes in groundwater head for the three vertical layers represented in the MODFLOW model were evaluated as part of the water supply assessment. Groundwater head corresponds with the elevation of the water table. Projected changes in mean groundwater head for the central tendency scenario (2030s CMIP3 and CMIP5 as well as 2070s CMIP3 and CMIP5) are summarized in Table 3-11. Groundwater head is projected to increase by between 1.8 and 7.8 feet for the 2030s (central tendency) and between 4.4 and 8.2 feet for the 2070s.

**Table 3-11. Average change in groundwater head due to MODFLOW simulations based on projected changes in all variables for the central tendency projection**

| Central Tendency Projected Change (in feet) | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| Change in Head, All, Layer 1 | 3.1 | 7.8 | 8.2 | 7.7 |
| Change in Head, All, Layer 2 | 2.0 | 5.0 | 4.9 | 4.8 |
| Change in Head, All, Layer 3 | 1.8 | 4.6 | 4.4 | 4.3 |

Note: “All” variables include recharge and max ET

Figure 3-38 focuses on layer 1 and shows how projected changes in groundwater head (in feet) for the central tendency compare with other HDe scenarios. Layer 1 is presented because it has the greatest sensitivity to projected climate changes. The wetter scenarios (HW and WW) generally indicate larger increases in groundwater head than the central tendency, while the drier scenarios (HD and WD) indicate smaller increases or even decreases in groundwater head, depending on the type of projection (CMIP3 or CMIP5) and time horizon (2030s or 2070s).

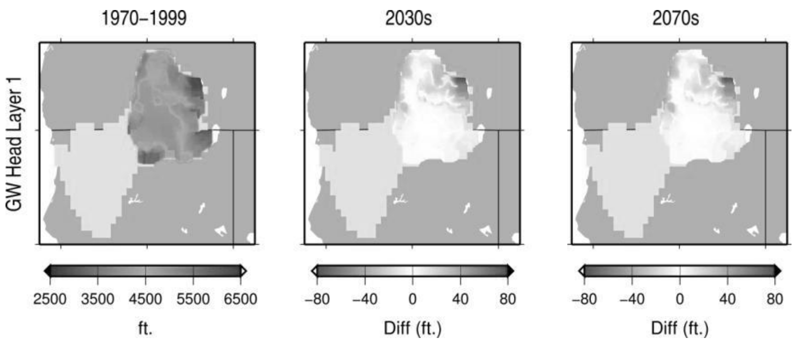



Notes:

1. The heavy black line represents median of values across the roughly 32,000 cells within the MODFLOW model domain (MODFLOW spatial resolution), while the boxes represent 25 and 75 percentile values, and whiskers represent 5 and 95 percentile values.
2. H = historical, CT = central tendency, WW = warm wet, WD = warm dry, HW=– hot wet, HD = hot dry.

**Figure 3-38. Summary of difference in projected mean groundwater head for MODFLOW model layer 1 for 2030s and 2070s time horizons compared with the historical baseline period of 1970–1999 water years**

Projected changes in groundwater head for layer 1 for the CMIP5-based central tendency scenario are presented spatially in Figure 3-39. The left column illustrates historical mean seasonal groundwater head over the simulation period 1970–1999 (water years), while the middle and right columns illustrate projected changes in feet for the 2030s and 2070s, respectively. The figure shows that projected changes may result in a substantial depth of water, up to about 50 feet in the northeast portion of the basin. As a point of reference, land surface elevations in the Upper Klamath Basin modeled domain range from 2,500 feet to 8,500 feet.




Note: The left-hand column illustrates the historical values, while the middle column and right-hand column illustrate change (in feet) from 1970–1999 values to the 2030s and 2070s, respectively.

**Figure 3-39. Comparison of change in mean groundwater head in the uppermost layer of the MODFLOW model for the central tendency climate scenario, using groupings of GCMs from CMIP5**

The following analysis summarizes projected discharge to individual stream reaches across the Upper Klamath Basin, as defined in Figure 3-40. Projections summarized in Table 3-12 indicate increases in groundwater discharge for all designated stream reaches. Similar to projections of precipitation and recharge, CMIP5 projections for the 2030s show larger increases than CMIP3 projections, while for the 2070s CMIP3 projections show larger increases than CMIP5. Also, CMIP3 2030s projections show the greatest change overall (even greater than for the 2070s). As previously discussed, the relative differences between scenarios are a result of the process of grouping GCM projections as part of the HDe approach. The smallest projected increases are for Lost River and Wood River reaches, while the largest projected increases are for Sycan and Sprague River reaches.

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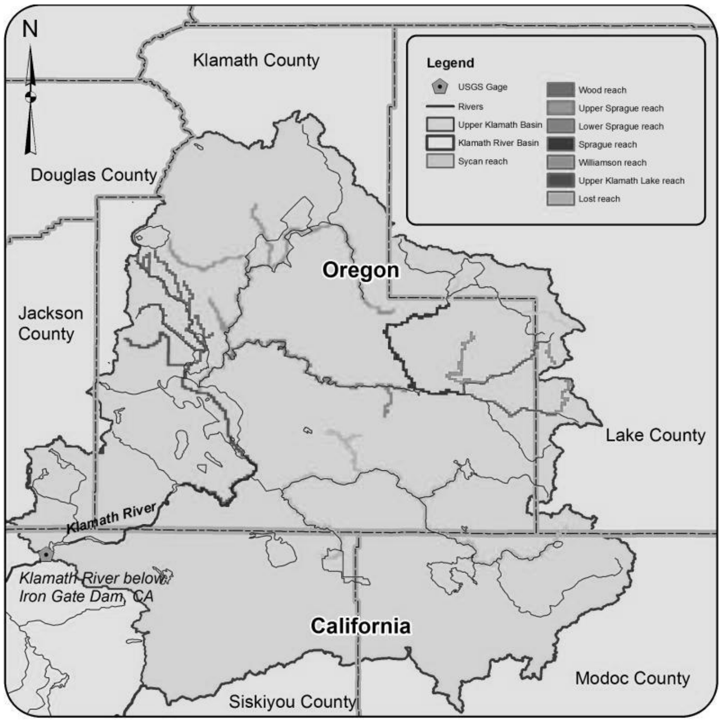



**Figure 3-40. Overview map of MODFLOW stream reaches analyzed as part of the Klamath River Basin Study water supply assessment**

**Table 3-12. Average percent change in groundwater losses to streams over the simulation period for central tendency projections**

| Central Tendency Projections (Percent Change) | CMIP3 2030s | CMIP5 2030s | CMIP3 2070s | CMIP5 2070s |
|---|---|---|---|---|
| Lost River | +0.7% | +2.6% | +1.9% | +1.7% |
| Lower Sprague | +2.8% | +6.5% | +6.8% | +5.3% |
| Sprague | +3.5% | +9.1% | +8.7% | +8.0% |
| Sycan | +5.2% | +13% | +13% | +12% |
| Upper Klamath Lake | +1.2% | +3.5% | +4.0% | +3.6% |
| Upper Sprague | +2.6% | +7.4% | +6.8% | +6.7% |
| Williamson | +2.7% | +6.9% | +7.6% | +6.2% |
| Wood River | +1.0% | +3.0% | +3.6% | +3.1% |

***3.7.4.2 Scott Valley***

The groundwater screening tools developed for the Scott and Shasta Valleys allow for the evaluation of projected changes in mean groundwater elevation. Figure 3-41 illustrates projected changes in monthly groundwater elevations for the two future time periods based on CMIP5 (panels a and b). Individual boxes in each panel represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. The historical simulation period is calendar years 1980–1999, while the future simulation period is effectively a 50-year period that represents the characteristics of the chosen future time horizon (2030s or 2070s, in this case). Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period in the absence of any changes in groundwater use beyond that associated with population growth. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases.

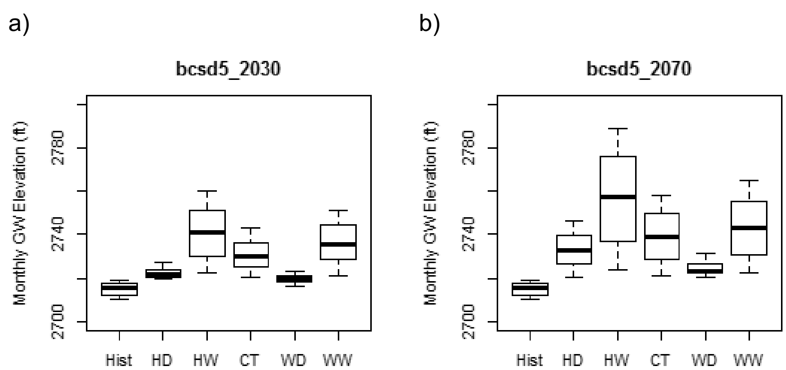



**Figure 3-41. Summary of projected groundwater elevation for Scott Valley**

The central tendency projections fall in between, with a median projection of a 15 foot increase in groundwater elevation by the 2030s and a 23 foot increase by the 2070s. To provide some context, the Scott and Shasta Valleys experienced fluctuations in annual groundwater elevation of about 20 feet over the period 1980–1999. Projected increases in groundwater elevation in the Scott Valley correspond with projected increases in precipitation in the watershed. Projected increases in actual ET computed by the VIC surface water hydrologic model (based on an assumption of natural vegetation) are not great enough to offset the projected increases in precipitation, resulting in greater potential for groundwater recharge.

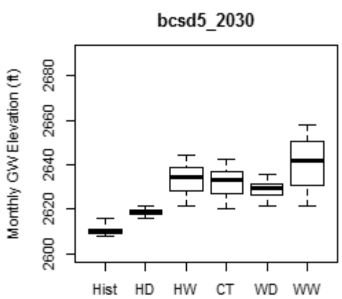
It is notable that the HW scenario based on CMIP5 indicates a greater increase in groundwater elevation than the cooler (WW) scenario. One would expect the HW scenario to have a smaller increase in groundwater elevation due to greater ET losses. However, the HW scenario may actually be wetter than the WW scenario, which may compensate for any additional ET losses due to higher temperatures.

CMIP3- and CMIP5-based projections are similar for the two future time horizons; however CMIP5-based projections generally result in greater increases in groundwater elevation, corresponding with greater increases in precipitation compared with CMIP3. Individual scenarios may also differ to due to the automated selection process for individual GCM projections within a quadrant (refer to Section 3.5.1.1, Climate Projections for additional explanation of the projection selection procedure).

#### *3.7.4.3 Shasta Valley*

Projected changes in monthly groundwater elevation for the Shasta Valley are summarized in Figure 3-42 (panels a and b) for the two future time periods based on CMIP5. Box plots are similar to those in Figures 3-41 and represent the 5th, 25th, 50th, 75th, and 95th percentiles of monthly values over the simulation period. Statistics for the future simulations may be compared with those from the historical simulation to gain an understanding of potential climate change impacts on groundwater elevations in the Shasta Valley.

The box plots show that projected monthly groundwater elevations for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. The central tendency scenarios based on CMIP5 indicate about a 24-foot increase in groundwater elevation for the 2030s and a 25-foot increase for the 2070s, compared with the historical baseline. To provide context, historical Shasta Valley groundwater elevations fluctuated approximately 20 feet over the historical simulation period. The wetter scenarios (HW and WW) indicate greater increases in groundwater elevation, while drier scenarios (HD and WD) indicate smaller increases. The WW scenario indicates the greatest projected change, likely because ET rates are probably lower than in the hotter scenarios and more water may be available for groundwater recharge.



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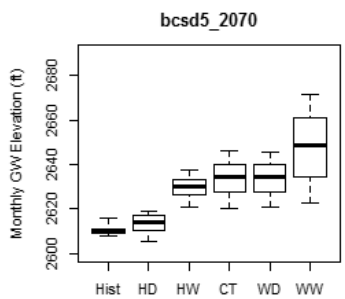

b)

**Figure 3-42. Summary of projected groundwater elevation for Shasta Valley**

A majority of the projections for the 2070s show greater increases in groundwater elevation than for the 2030s, with the exception of the hotter scenarios (for example, CMIP3-based HD and CMIP5-based HD and HW). A smaller increase in groundwater elevation in the 2070s compared with the 2030s, despite greater projected increases in precipitation, may be due to the combined effects of increased ET corresponding with higher temperatures.

When comparing CMIP3-based projections with CMIP5-based projections, the differences in median projections of monthly groundwater elevation are more dissimilar than would be expected. For example, the median monthly change in groundwater for the 2070s compared with the historical baseline is almost 5 feet for CMIP5 and 12 feet (more than double) for CMIP3. This example illustrates the importance of considering a wide range of climate scenarios (including both CMIP3 and CMIP5) in the analysis of water supply impacts.

## Future Availability – Scott and Shasta Valley Groundwater

Projected monthly groundwater elevations in the Scott and Shasta Valley alluvial aquifers (as defined by CDWR Bulletin 118) for the 2030s and 2070s may be higher than for the historical period, in the absence of any changes in groundwater use beyond that associated with population growth. However, the projected changes are within or close to the historical fluctuations in groundwater elevation in the two basins (on the order of 20 feet for both basins).

## 3.8 External Factors Affecting Water Supply

In addition to detailed analysis of historical and projected surface and groundwater supplies, this chapter also discusses existing knowledge and research regarding historical and projected sea level rise and wildfire risk. We acknowledge that these phenomena have and may continue to change due to projected changes in climate, and they are important considerations when analyzing water supplies in the Klamath River Basin. Sea level rise poses many risks to the coastal landscape and population. Projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things.

### 3.8.1 Projected Sea Level Rise

A warming climate causes global sea level to rise by two primary mechanisms: increasing ocean volume due to expanding sea water associated with warming, and the melting of land ice. Other, more regional phenomena impact the extent of sea level rise off the coast of Oregon and California. For instance, climate patterns such as El Niño and the PDO affect winds and ocean circulation, raising local sea level during warm phases (e.g., El Niño) and lowering sea level during cool phases (e.g., La Niña). Large El Niño events can raise coastal sea levels by 4 to 12 inches for several winter months (NRC, 2012). Tectonics may also affect regional sea levels. In some regions, tectonics may cause the land surface to rise in some regions and fall in others, indicating rising and falling sea levels, respectively. For example, records from 12 west coast tide gages indicate local variability in sea-level change along the coast, although most of the gages north of Cape Mendocino, California, show that relative sea level has been falling over the past 6–10 decades (NRC, 2012). Sea level projections due to climate change are confounded by changes due to naturally occurring phenomena described above.

This section summarizes the findings from three primary documents describing the impacts of climate change on sea level rise in the coastal region of the Klamath River Basin. The first is a 2012 assessment by the National Research Council of best available science with respect to sea level rise in California, Oregon, and Washington. The second document is the Public Draft Report of the most recent National Climate Assessment, which was published in 2013. At the completion of the Klamath River Basin Study water supply assessment, the final National Climate Assessment Report was yet not complete. The third document is the State of California Sea Level Rise Guidance Document, which was published in 2013 by the Coastal and Ocean Working Group of the California Climate Action Team. This document provides guidance for incorporating sea-level rise projections in planning and decision-making for projects in California, but also summarizes existing knowledge on projected sea level rise.

National Research Council (2012) summarized past and projected sea-level rise for the coasts of California, Oregon, and Washington. The assessment states that

vertical land motion from geological processes and human activities, estimated by global positioning system (GPS) measurements, show that much of the western coast north of Cape Mendocino (including the coastal region of the Klamath River Basin) is rising about 0.06–0.1 inches per year (NRC, 2012). Flooding and erosion in coastal areas is already occurring and is damaging some areas of the California coast during storms and extreme high tides (Garfin et al., 2014). Rising land masses may exacerbate the issue of coastal flooding and erosion.

Projections for the Washington, Oregon, and California coasts north of Cape Mendocino indicate that sea level is projected to change between -2 inches (sea-level fall) and +9 inches by 2030, between -1 inch and +19 inches by 2050, and 4–56 inches by 2100 (NRC, 2012). Sea level is likely to rise at a greater rate during the 21st century than it has in the 20th century. Figure 3-43 illustrates projected sea level rise (in centimeters) along the entire west coast of the U. S.

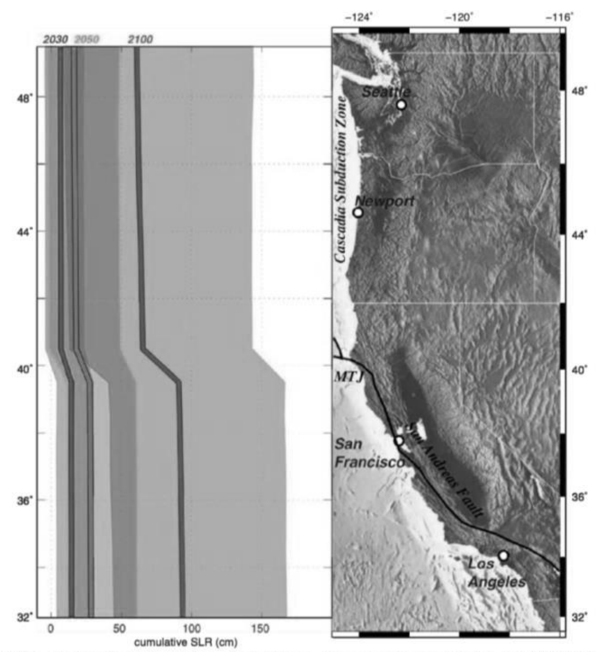


FIGURE S.1 Projected sea-level rise off California, Oregon, and Washington for 2030 (blue), 2050 (green), and 2100 (pink), relative to 2000, as a function of latitude. Solid lines are the projections, and shaded areas are the ranges. Ranges overlap, as indicated by the brown shading (low end of 2100 range and high end of 2050 range) and blue-green shading (low end of 2050 range and high end of 2030 range). MTJ = Mendocino Triple Junction, where the San Andreas Fault meets the Cascadia Subduction Zone.

*Source: NRC, 2012, Figure S.1*

**Figure 3-43. Projected sea level rise along the west coast of the United States**

Risks associated with projected sea level rise include the increased risk of coastal flooding, storm surge inundation, coastal erosion and shoreline retreat, and wetland loss. NRC (2012) highlights the significant risk posed to the region north of Cape Mendocino from a large earthquake (magnitude greater than 8) along the Cascadia Subduction Zone, which could cause significant land subsidence resulting in instantaneous sea-level rise as well as a tsunami. In addition, many coastal wetlands, tidal flats, and beaches will likely decline in quality and extent as a result of sea level rise.

### 3.8.2 Projected Wildfire Risk

The sections of the Public Draft of the most recent National Climate Assessment most relevant to the area of this study (Garfin et al., 2013 for the southwest U.S.; Mote et al., 2014 for the northwest U.S.) summarize past and projected trends in wildfire risk along the west coast, including the greater region surrounding the Klamath River Basin. Increased warming, due to climate change, and drought have increased wildfires and impacts to people and ecosystems in the Southwest, including California. A number of studies have documented increases in wildfire fire season duration and fire frequency and project increases in the probability of large wildfires. Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s (Mote et al., 2013). Between 1970 and 2003, warmer and drier conditions increased the burned area in western U.S. mid-elevation conifer forests by 650 percent (Westerling et al., 2006). Models project up to 74 percent more fires in California in the future (Westerling et al., 2012).

Some of the causes of increased wildfire risk include projected decreases in late summer stream flows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. Potential increases in water deficits may increase tree stress and mortality, tree vulnerability to insects, and fuel flammability (Mote et al., 2013). Also, an increased risk of watershed vegetation disturbance is anticipated due to increased wildfire potential (Interior and CDFG, 2011).

## 3.9 Uncertainties Associated with Impacts Assessment Approach

In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a "cascade of uncertainty" (IPCC 2007, here), although there may be situations where one model's tendency to over- or under-estimate may be countered at least to some extent by another's tendency to err in the other direction. While this study has not developed an estimate of the cumulative

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uncertainties in the results based on this methodology, this section summarizes uncertainties associated with various aspects of the Klamath River Basin Study water supply assessment, including the use of climate change scenarios as well as surface and groundwater hydrologic models to evaluate climate change impacts. Additional discussion regarding the use of GCM climate projections and applied downscaling techniques is provided by Reclamation (2011d). The nature of these uncertainties is only briefly described below.

### 3.9.1 Global Climate Projections, Modeling, and Downscaling

The climate projections considered in this report represent a range of future greenhouse emission pathways (Reclamation, 2011d); however, uncertainties associated with estimating these pathways, including those introduced by assumptions of global growth and land use, are not explored in this analysis. Additional uncertainty is associated with feedbacks such as the influence of human-produced aerosols in the atmosphere.

GCMs themselves have associated uncertainty with respect to their initial conditions, inputs, representation of physical processes, and assumptions regarding the sensitivity of climate variables to changes in greenhouse gas concentrations and other parameters. Issues with GCMs are compounded by the fact that it is currently difficult, if not impossible, to validate GCM results using datasets that were not used to develop and tune these GCMs. Different simulations using the same model may have quite different realizations of longer timescale climate patterns. Regarding representation of physical processes, the most recent generation of GCM simulations (based on CMIP5) incorporate, in many cases, improved understanding of the climate system. By using both CMIP3- and CMIP5-based projections as part of the Klamath River Basin Study water supply assessment, we may evaluate the differences in results based on a wider range of model constructs. GCMs may have biases toward being too wet, too dry, too warm, or too cool, and these should be identified and accounted for in climate change impacts studies (Reclamation, 2011d). Although there is very high confidence that the CMIP5 models show long-term trends consistent with historical observations, there is substantial (several-fold) disagreement between models and observations over the rate of warming for 1998-2012. For example, Bindoff et al. (2013) acknowledge that the observed global mean surface temperature has shown a much smaller increasing linear trend over 1998-2012 than the suite of CMIP5 models, despite the fact that half of this period was included in the data that was used to develop/tune the models. Due to internal climate variability, in any given 15-year period the observed trend in the global mean surface temperature sometimes can lie near one end of a model ensemble.

The uncertainty due to the mismatch between simulated mean global surface temperature and observations is exacerbated by the fact that the reliability of model results declines and uncertainty expands as one goes from the global scale to finer (i.e., regional and local) scales as is necessary to do an analysis for the Klamath River Basin. This is particularly true for precipitation.

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(2) US Climate Change Science Program. Climate Models: An Assessment of Strengths and Limitations. Washington, DC: U.S. Climate Change Science Program and the Subcommittee on Global Change Research; 2008.

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Generally, to reduce inconsistencies between simulated climate and observed conditions, projections are bias corrected. The term bias correction refers to the use of a statistical procedure to adjust global climate model projections to remove differences between simulated and observed climate conditions computed over a common historical time period. This method, however, assumes that biases are systematic and their distributions over the historical time period would be similar to a future time period. Primary causes of bias in global climate model simulations include bias resulting from the coarse resolution of global climate models and the corresponding inability to resolve important stationary features such as land surface topography and land-water interfaces along coastlines and the use of simplified parameterizations to represent physical processes that occur at too small a scale or are too complex to be represented physically. They could also result from biases in emission inputs, coupled biogeochemical models and estimates of climate sensitivity. Model biases can significantly affect impact studies that use climate projections to evaluate hydrologic and ecosystem response to potential changes in climate. As a result, it is prudent to apply bias correction before using global climate model outputs as inputs to other types of models, recognizing that other uncertainties persist.

Uncertainties are also associated with the methodology used to downscale information at the scale of GCMs to the regional, or watershed, scale. The Klamath River Basin Study utilizes statistically downscaled climate projections to derive HDe climate scenarios. Although these types of scenarios have been used to support numerous water resources impacts studies, uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies, such as statistical downscaling, require historical reference information use on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which presumably would change somewhat with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have statistical stationarity. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

### 3.9.2 Watershed Vegetation Changes under Climate Change

In Reclamation (2011d) and related literature sources cited, the chosen approach for assessing hydrologic effects under projected climate changes is to use a surface water hydrologic model that computes hydrologic conditions, given

changes in weather, while holding other watershed features constant. The composition of vegetation might change as climate changes, and that, in turn, would affect runoff through changes to evapotranspiration and infiltration processes.

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### 3.9.3 Direct Effects of Carbon Dioxide on Water Use in Vegetation

Increases in CO2 concentrations also affect vegetation growth, and water use and demand in a variety of other ways. Higher CO2 levels increase biomass production via an increase in the photosynthetic rate, unless there are nutrient limitations. They also increase the intrinsic water use efficiency (WUE) of plants, that is, they transpire (or discharge) less water to the atmosphere per unit biomass product. The latter then would decrease demand for irrigation water, and increase runoff, soil moisture and groundwater recharge, unless the transpiration effect is swamped by a countervailing increase in biomass production (AR5, WG2, Chapter 4, 276; IPCC 2014, 161). In managed systems, but not in unmanaged systems, the amount of biomass production can be controlled, and nutrient limitations on photosynthesis can be surmounted, if desired.

The IPCC notes that a meta-analysis of studies at 47 sites across five ecosystem types suggests that intrinsic WUE for mature trees increased by 20.5% between the 1970s and 2000s. It also notes that other studies have detected an increase in intrinsic WUE at several forest sites and a temperate semi-natural grassland since 1857 but the increase stopped in one boreal tree species after 1970 (AR5, WG2, Chapter 4, 294). In addition, a study of 21 forest sites in the Northern Hemisphere, including 7 unmanaged forests in the midwestern and northeastern U.S., found that carbon uptake and WUE had increased at the majority of sites for the periods examined (7-18 years) (Keenan et al. 2013). That study also found that observed increase in forest water-use efficiency was larger than predicted by existing theory and 13 terrestrial biosphere models.

Based on experimental results and modeling studies, the IPCC states that it has “medium confidence that increases in CO2 up to about 600 ppm will continue to enhance photosynthesis and plant water use efficiency (WUE), but at a diminishing rate” (AR5, WG2, Chapter 4, 287), and it classifies these effects as “first-order” influences on ecosystem and hydrological responses to anthropogenic climate change (AR5, WG2, Chapter 4, 288).

However, the IPCC notes that since “… water, carbon, and vegetation dynamics evolve synchronously and interactively under climate change, it remains a challenge to disentangle the individual effects of climate, CO2, and land cover change on the water cycle.” (IPCC 2014, 160). Because of the complexities involved in modeling these effects, the Klamath River Basin Study did not factor changes in water demand, runoff, soil moisture and groundwater recharge due to the direct effects of CO2. Consequently, this is a substantial source of uncertainty that should be considered by users of this study.

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Sources:

1. AR5, WG2, Chapter 4.

2. IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summaries, Frequently Asked Questions, and Cross-Chapter Boxes. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. World Meteorological Organization, Geneva, Switzerland, 190 pp. 160 (See p. 160 for recharge).

3. Keenan TF, Hollinger DY, Bohrer G, Dragoni D, Munger JW, Schmid HP, Richardson AD. Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. Nature. 2013 Jul 18;499(7458):324-7.

### 3.9.4 Quality of Hydrologic Model Used to Assess Hydrologic Effects

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In Reclamation (2011d) and most of the cited literature sources, the chosen approach for assessing surface water hydrologic effects has typically involved using surface water hydrologic models, which may not represent key hydrologic processes related to groundwater and/or large water bodies. Reclamation (2011d) discusses these limitations, and they are illustrated in Section 3.3.2, Historical Surface Water Availability – Approach, which shows how the VIC model imperfectly reproduces historical runoff conditions. Some of these imperfections could be reduced through refined redevelopment, or calibration, of the model. Another approach for exploring the uncertainty associated with the VIC hydrologic model, which was not taken in this study, would be to apply additional surface water hydrology models and compare results across simulations.

In the case the Klamath River Basin, refinement of VIC model calibration is challenging due to the lack of available naturalized flow datasets. Reclamation (2005) showed the difficulty in developing naturalized flows in such a complex watershed. Additional efforts may be invested in this area; however, focusing on a change of projected future conditions relative to historical conditions is a scientifically defensible approach taken in numerous climate change impacts studies, and is the approach taken for the Klamath River Basin Study water supply assessment.

### 3.9.5 Quality of Groundwater Models Used to Assess Groundwater Effects

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Groundwater modeling in general is extremely challenging due to the complexity of most groundwater systems (the Klamath River Basin included) coupled with a general lack of sufficient data to characterize groundwater basins in great detail. The USGS has made great efforts in collecting data and developing a fine scale finite-difference MODFLOW model for the Upper Klamath Basin (Gannett et al., 2012). Despite the high level of effort taken in this study, significant uncertainties still remain about the adequacy of the model to characterize detailed groundwater dynamics in the basin. Gannett et al. (2012) discuss possible reasons for differences between observed and simulated groundwater elevations in parts of the basin, including lack of accurate information on rates and locations of pumping, and coarse vertical discretization of the model relative to the gradients of groundwater flow. Nonetheless, we may assume that historical biases in the MODFLOW model may carry through to the future. As such, we may evaluate the relative change of projected groundwater elevations and discharge compared with the historical simulation.

The Scott and Shasta Valleys have greater issues of data availability for characterizing the groundwater systems than the Upper Klamath Basin, where more resources have been invested in monitoring and evaluating the groundwater system. Monitoring wells are few and the monitoring data available for those wells is sparse, generally consisting of two or so measurements per year. In addition, CDWR Bulletin 118 was used to define groundwater basins in these regions, and these likely do not represent the complexity of groundwater aquifers that exist there. Development of groundwater models for these basins using this information poses a challenge. Furthermore, the size of these groundwater basins is much smaller than the Upper Klamath Basin, making the coarse spatial resolution of groundwater model inputs (such as precipitation, temperature, and gridded runoff) less relevant at the scale of these sub-basins. Due to these high levels of uncertainty, a statistical modeling approach was taken to simulate groundwater elevations in the Scott and Shasta Valleys. A simpler approach may be justified when uncertainty associated with input data is high. Still, the statistical models may be used to evaluate the relative change of projected groundwater elevations compared with estimated historical conditions.

### 3.9.6 Differences between Climate Projections from CMIP3 and CMIP5

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The above discussions of uncertainty related to climate forcings and downscaling techniques are based on analysis of projections from CMIP3. The models and scenarios of emissions used in CMIP5 differ in several ways from those used in CMIP3. First, model resolution has generally increased by a factor of 2 (i.e., CMIP5 models have, on average, twice the number of grid cells representing the atmosphere than CMIP3 models). Second, although many of the models used in CMIP5 are similar in structure to those used in CMIP3, many incorporate updated physics and added, or improved, individual process representation. Some of the models used in CMIP5 reflect a fundamental advancement in model structure by

incorporating biogeochemical cycling; this new class of models is referred to as Earth System Models. Third, there are notable differences in precipitation for some regions (e.g., greater warming over the Upper Columbia Basin, less precipitation over the northern Great Plains, and more precipitation over California and the Upper Colorado Basin). Projections showing wetter portions of California and the Upper Colorado are notable because they challenge the prevailing perspective of climate change impacts to the region that has been held since 2007 (informed by CMIP3 projections): namely, that these regions will become drier, resulting in reduced runoff. It is important to recognize that while CMIP5 offers new information, more work is required to better understand CMIP5 and its differences compared to CMIP3. In some regions, model resolution is likely the leading factor in these differences. In the North American Monsoon region, for example, the higher resolution of CMIP5 models allows these models to better capture the landward moisture transport and overland convection that results in monsoon precipitation events. These processes were not resolved in the lower resolution CMIP3 models.

The CMIP5 projections represent a new opportunity to improve our understanding of climate science, which is evolving at a rapid pace. While CMIP5 projections may inform future analyses, many completed and ongoing studies are informed by CMIP3 projections that were selected as the best information available at the time of the study. Even though CMIP5 provides the latest available suite of climate projections, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 projections. Current state of practice relies on one or both suites of climate projections for use in impacts studies.

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# Chapter 4
# Klamath River Basin Study
# Assessment of Current and Future Water Demands

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# Chapter 4 Assessment of Current and Future Water Demands

## 4.1 Introduction

Changes in water demands in the Klamath River Basin over the next 50 years are uncertain, and will depend on a number of socioeconomic and other factors. The Klamath River Basin Study aims to assess the impacts of climate change on water supply and demand in the watershed from its headwaters to the mouth, and to identify current and projected water supply shortages. This chapter of the Klamath River Basin Study report quantifies current water demand and projected future water demand in a changing climate. Future demand projections are meant to be sufficiently broad to capture the plausible ranges of uncertainty. Projected water demands are evaluated along with the projected supply conditions in Chapter 3 as part of a system reliability analysis to identify potential water supply shortages in the Klamath River Basin, which is presented in Chapter 5. The system reliability analysis, presented in Chapter 6, identifies any potential shortfalls between demand and supply, as well as potential strategies to plan for and reduce gaps.

Statistically downscaled climate projections from general circulation models (GCMs) inform both the demand and supply analyses. As discussed in Chapter 3, two sets of downscaled GCM output were used in the analyses: Coupled Model Intercomparison Project Phase 3 (CMIP3) and Coupled Model Intercomparison Project Phase 5 (CMIP5). The main components of the Klamath River Basin Study and their interaction with developed climate change scenarios are shown in Figure 4-1. The ensemble hybrid delta (HDe) period change method (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d) described in Chapter 3 was used to assess the impacts of climate change on demands. The future periods used for the Klamath River Basin Study are the 2030s and 2070s (represented as the mean over 2020–2049 and 2060–2089, respectively) and the historical baseline period used for the analyses is 1950–1999.

Some of the analyses described in this chapter are based on previous work done as part of Reclamation's West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). WWCRA is a component of the Department of the Interior WaterSMART Program that was implemented to meet requirements of the Secure Water Act (Public Law 111-11, Sections 9501-9510).[6]

[6] http://www.usbr.gov/WaterSMART/wcra/index.html

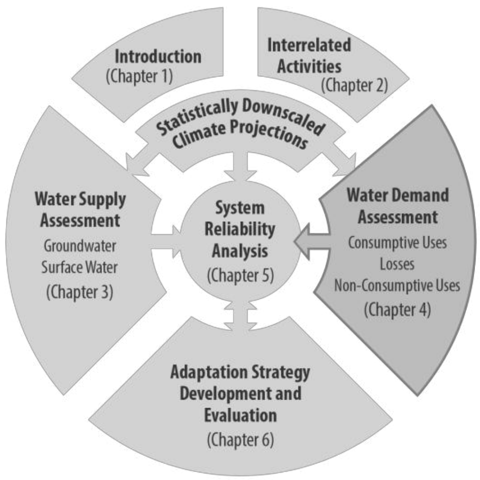


**Figure 4-1. Overall approach of Klamath River Basin Study, highlighting Chapter 4**

### 4.1.1 Description of Water Demands

Water demands are typically associated with one or more water uses that can be consumptive or non-consumptive. Consumptive water use results in a loss of water from the supply system, often associated with human activities. Examples of consumptive uses include manufacturing, agriculture, and food preparation where water is not returned to the supply system. Evaporation from water bodies such as reservoirs is another type of consumptive use that is more typically considered a loss. Non-consumptive uses are those which do not deplete the water supply. There are many types of non-consumptive uses; significant examples relevant to this study include hydropower generation, environmental resources, recreation, and aquaculture. Municipal and industrial (M&I) and rural domestic demands are typically comprised of both non-consumptive and consumptive uses. Another significant demand category relevant to the study is tribal demands, which are also comprised of both consumptive and non-consumptive uses.

#### Definition of Terms

**Demand** – Water needed to meet identified uses.

**Consumptive Use** – Water use resulting in a loss of available water supply, often associated with human activities.

**Loss** – Reduction of available water supply due to evaporation and operation inefficiencies.

**Non-Consumptive Use** – Water use not resulting in reduction of available water supply.

The focus of the Klamath River Basin Study is the assessment of current and future demands with respect to consumptive uses (both human-influenced and natural) and losses. Non-consumptive demands are either discussed qualitatively in this chapter or are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6.

### 4.1.2 Previous Studies

Many previous studies have quantified various types of water demand in all or part of the Klamath River Basin. Table 4-1 identifies the references that were reviewed in development of the water demands assessment. In the case of agricultural irrigation and reservoir evaporation, we utilized methods described by Reclamation (2014) in order to maintain consistency with approaches used in other western U.S. watersheds.

The following sections discuss current and future water demands, and detail how previous studies were used and whether the analysis was quantitative or qualitative.

**Table 4-1. Summary of demand categories and related previous studies**

| Demand Categories | Primary Information Source(s) | Domain |
|---|---|---|
| **Human Influenced Consumptive Uses** | | |
| Agricultural irrigation | Reclamation WWCRA (2014) | Western U.S. |
| | | U.S. Counties |
| | HDR (2008) | Oregon |
| | CDWR (2009) | California |
| | Cuenca (1992) | Upper Klamath Basin (Oregon) |
| | Gannett et al. (2007) | Upper Klamath Basin |
| | Reclamation (2005b) | Klamath Project area |
| Municipal & Industrial | CDM (2010) | Klamath Falls, OR |
| | SHN (2004) | Hayfork, CA |
| | Pace (2011) | Weaverville, CA |
| | Pace (2004) | Weed, CA |
| | Tully and Young (2010) and Pace (2006) | Yreka, CA |
| | The USGS Water Use Program (http://water.usgs.gov/watuse/; Kenny et al., 2009) | U.S. Counties |
| | HDR (2008) | Oregon |
| | CDWR (2009) | California |
| Rural Domestic | USGS Water Use Program | U.S. Counties |
| Tribal | Interior and CDFG (2012) | |

**Table 4-1. Summary of demand categories and related previous studies**

| Demand Categories | Primary Information Source(s) | Domain |
|---|---|---|
| **Other Consumptive Uses and Losses** | | |
| Wetlands | Stannard et al. (2013) | Upper Klamath Basin |
| | Mayer and Thomasson (2004) | Lower Klamath NWR |
| | Bidlake (2002) | Tule Lake NWR |
| Evaporation from lakes and reservoirs | Reclamation WWCRA (2014) | Western U.S. |
| | Bidlake (2000), Bidlake and Payne (1998), Janssen and Cummings (2007), and Stannard et al. (2013) | |
| **Non-Consumptive Uses** | | |
| Environmental Resources | See Section 4.2.3.2, Environmental | |
| Hydropower | See Section 4.2.3.3, Hydropower | |
| Recreation | See Section 4.2.3.1, Recreation | |
| Aquaculture | See 4.2.3.4, Aquaculture | |

## 4.2 Current Demands

Historical and current consumptive water uses and losses were quantified through findings from previous studies and model simulations and evaluated in order to compare with potential future changes due to climate change. Non-consumptive uses are briefly discussed; however, these uses are quantified in the modeling supporting the system reliability analysis in Chapter 5. Identified non-consumptive needs are addressed as measures for evaluation of climate change impacts and implementation of adaptation strategies in Chapter 6. The current demands considered in this chapter are listed in Table 4-2 along with the sources or models used to provide an estimate for the Klamath River Basin Study. Each of the demands evaluated in this chapter, and the associated estimates used, are discussed in the sections that follow.

Current Human Influenced Consumptive Uses

Based on analyses supporting the Klamath River Basin Study, total consumptive water demand for human uses in the basin is about 800,000 acre-feet/year and about 98 percent of the total human influenced demand is for agricultural irrigation.

### 4.2.1 Human Influenced Consumptive Uses

Consumptive uses for human needs in the Klamath River Basin Study demands assessment have been quantified using a variety of existing sources as well as

model simulations. Table 4-2 summarizes the categories for which demands have been quantified, showing primary sources of data and models used.

One existing source of consumptive use information, which was used in conjunction with other sources described later, is the countywide USGS Water Use Program data. This is arguably the most comprehensive source of existing water use information for the study area (including both consumptive and non-consumptive uses). The most current data available are typically for 2005 and 2010, but more recent data were available in a few cases.

## Current Human Influenced Consumptive Use Estimate Sources

Human influenced consumptive use estimates are based in part on USGS data, but this study uses WWCRA based model simulations for agricultural demands

**Table 4-2. Summary of demand categories evaluated by the Klamath River Basin Study Assessment of Current and Future Water Demands and data and methods used**

| Demand Categories | Data Sources Used | Methods Used |
|---|---|---|
| **Human Influenced Consumptive Uses** | | |
| Agricultural irrigation | Reclamation WWCRA (2014) | ET Demands Model (further described in corresponding section) |
| Municipal & industrial | Municipal water plans and USGS Water Use Program (see references in Table 4-1) | Statistical models and historical information |
| Rural domestic | USGS Water Use Program | Statistical models and historical information |
| Tribal | Addressed as part of agricultural, M&I, and Rural Domestic demand categories | |
| **Other Consumptive Uses and Losses** | | |
| Wetlands | Stannard et al. (2013) | ET Demands Model and empirical relationships |
| Evaporation from lakes and reservoirs | Reclamation WWCRA (2014) | Complementary Relationship Lake Evaporation (CRLE) model |

Included in Table 4-3 are 2005 USGS usage estimates for Siskiyou and Trinity Counties in California, Klamath County, Oregon, and the portion of Modoc County, California within the Klamath River Basin.[7] The total basin demand is approximately 1.2 million acre-feet per year (AFY). Note that Table 4-3 values are not all-inclusive since Del Norte and Humboldt Counties in the California portion of the basin are not included. Estimates for these counties are not

[7] http://water. usgs.gov/watuse/

included since only a very small portion of their water demands (estimated between 1 and 2 percent) occur within the basin. The in-basin demands for these counties are discussed later under the specific demand category discussions. Also note that the USGS data do not include reservoir evaporation. Additionally, the uses reported in Table 4-3 include both consumptive and non-consumptive components of these uses. For example, municipal and industrial (M&I) use includes water that eventually returns to the river system via a wastewater treatment plant.

**Table 4-3. Summary of USGS 2005 Water Use Program estimates for the Klamath River Basin**

| Water Use Category (note: includes both consumptive and non-consumptive uses) | 2005 Use (AFY) |
|---|---|
| Surface water irrigation | 717,154 |
| Groundwater irrigation | 433,164 |
| Municipal and industrial | 18,204 |
| Rural domestic | 11,255 |
| Livestock | 2,903 |
| Mining and industrial/commercial | 2,868 |
| **Total (human influenced uses)** | **1,185,548** |

*Source: USGS Water Use Program*

The Klamath River Basin Study estimates of current human influenced consumptive uses in the watershed are based in part on the USGS Water Use Program data summarized above. However, in the case of agricultural irrigation demand (surface and groundwater), this study utilizes model simulations of agricultural water requirements following the approach of Reclamation's West Wide Climate Risk Assessment (WWCRA) (Reclamation, 2014). In the case of M&I and rural domestic water uses, more current (2010) estimates were made based on historical population trends. Also, the study focuses only on the consumptive portion of these demands, which is assumed to be 40 percent for both M&I and rural domestic demands and comprised of landscape irrigation (refer to Section 4.2.1.2, Municipal and Industrial).

Estimated current consumptive uses (including human influenced uses, wetland ET, and reservoir evaporation losses) by the Klamath River Basin Study are summarized in Table 4-4. These are estimated basin-wide uses that are the basis for assessment of projected changes in consumptive uses and losses for the two future time periods considered in this study, the 2030s and 2070s. Respective sections of this chapter provide details behind these estimates and the associated assumptions made. Note that the estimated reported M&I and rural domestic consumptive uses (see Table 4-4) are approximately 40 percent of the values reported by the USGS Water Use Program (see Table 4-3), which supports the

assumption by the Klamath River Basin Study regarding the consumptive portion of total M&I and rural domestic demand.

**Table 4-4. Estimated current basin-wide consumptive uses and losses as computed by the Klamath River Basin Study**

| Basin Wide Consumptive Uses and Losses | Estimated Mean Annual Quantity (AFY) |
|---|---|
| Agricultural irrigation (NIWR) | 755,734 |
| Municipal and industrial | 8,801 |
| Rural domestic | 4,537 |
| **Subtotal for Human Influenced Consumptive Use** | **769,072** |
| Wetland ET | 1,089,061 |
| Reservoir and lake evaporation | 181,297 |
| **Total Consumptive Uses and Losses** | **2,039,430** |

#### *4.2.1.1 Agricultural Irrigation*

Irrigation of croplands is by far the largest human influenced consumptive use in the Klamath River Basin, 97 percent[8] according to the USGS Water Use Program estimates (which include conveyance and on-farm losses) and approximately 98 percent[9] according to the Klamath River Basin Study estimates (which do not include conveyance and on-farm losses). Agricultural irrigation use typically includes crop demands, conveyance losses, and on-farm losses. Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, these losses were not calculated in this study.

> **ET Demands Model Methodology**
>
> The model calculates historical and future daily net irrigation water requirements using the FAO-56 dual crop coefficient method with crops, temperature, precipitation, wind, and soil inputs. Solar radiation and humidity are estimated from daily minimum and maximum temperature inputs.

Crop demands are consumptive. Conveyance and on-farm losses can be consumptive or non-consumptive. Examples of non-consumptive conveyance and on-farm losses include field runoff and deep percolation, since associated water generally returns to the supply system. An example of a conveyance or on-farm loss that is

[8] Computed as sum of 717,154AFY and 433,164AFY, divided by 1,185,548AFY (refer to Table 4-3).
[9] Computed as subtotal for human influenced consumptive uses 755,734AFY, divided by 769,072AFY (refer to Table 4-4).

consumptive is evapotranspiration by natural vegetation on farm lands or in and around canals.

This study focuses on the crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e., effective precipitation ($P_e$). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Allen et al., 1990). Crop water demand also does not include conveyance or on-farm losses.

Current NIWR estimates have been developed for this study. A discussion of recent irrigation demand estimates is presented first, followed by a discussion of the developed NIWR estimates.

**Recent Irrigation Estimates by Others**
Estimates by others are presented as background information and for comparison to those developed in the Klamath River Basin Study. As discussed previously, the USGS estimates that total irrigation water use for the basin in 2005 was 1,150,318 AF, including 717,154 AF from surface water sources and 433,164 AF from groundwater sources (Kenny et al., 2009). These estimates include irrigation of golf courses, parks, nurseries, cemeteries, and other self-supplied landscape-watering uses. The USGS estimates also include conveyance and on-farm water losses. Detailed information on how the USGS developed the 2005 irrigation estimates is provided in Dickens et al. (2011).

## Current Agricultural Irrigation Demand

Agricultural irrigation demands, in the form of net irrigation water requirement (NIWR), were simulated by the ET Demands model using current cropping data and average climate conditions for the period 1950–1999.

The CDWR estimates crop irrigation demands annually for the California portion of the Klamath River Basin (the Klamath Upper and Lower Planning Sub-area).[10] The CDWR estimates include NIWR and total water applied, which includes on-farm losses but not conveyance losses. The reported 2010 estimates for the California portion of the basin are 347,672 AF of NIWR and 482,504 AF total water applied (Coombe, 2013). It is estimated that approximately 62 percent of the total demand is met with surface water and 38 percent is met with groundwater sources.

The OWRD's recent Statewide Water Needs Assessment (HDR, 2008) includes a 2010 agricultural irrigation water use estimate for Klamath County, Oregon,

[10] http://www.water.ca.gov/landwateruse/anlwuest.cfm

which represents the approximate Oregon portion of the basin. The estimate is 730,000 AF and includes both on-farm and conveyance losses.

The sum of CDWR and OWRD estimates (1,212,504 AF) is greater than, though comparable to, the USGS estimate for total irrigation (1,150,318 AF). It is assumed the discrepancies are associated with which loss estimates were included and how they were estimated.

**Estimation of Net Irrigation Water Requirements**

Current and future NIWR estimates were developed for this study following the methods established by Reclamation's WWCRA. Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The current or baseline irrigation water demand estimates developed for this study are based on the most recent available crop data and climate conditions during the historical baseline period 1950 through 1999. Crop types and quantities reported for 2009 were provided by the Klamath Basin Area Office for Reclamation's Klamath Project lands, and crop data for the remainder of the basin were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service as reported for 2010.[11] The 1950 through1999 climate data used are from the same published data set by Maurer et al. (2002) discussed in Chapter 3. The values used from this data set were adjusted based on historical observations from 13 weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's twelve Hydrologic Unit Code eight-digit level drainage areas (HUC8 sub-basin). The HUC8 sub-basins are shown in Figure 4-2. The map also includes the estimated number of irrigated acres by HUC8 sub-basin. Point locations in the figure represent corresponding weather stations used to support the modeling effort, including those used for removing biases in the gridded meteorological dataset and those used for estimating dewpoint and windspeed across the HUC8 sub-basins. Table 4-5 provides additional details for some of these features. A full summary of weather station information is provided in Appendix C, Section 2.0. Appendix C, Section 3.0 summarizes the estimated percentage of crop acreage within each HUC8 sub-basin according to crop type.

[11] http://www.nass.usda.gov/research/Cropland/SARS1a.htm

17-01174_012539;17-01174_012539;17-01174_012540;17-01174_012541;17-01174_012542;17-01174_012543;1...



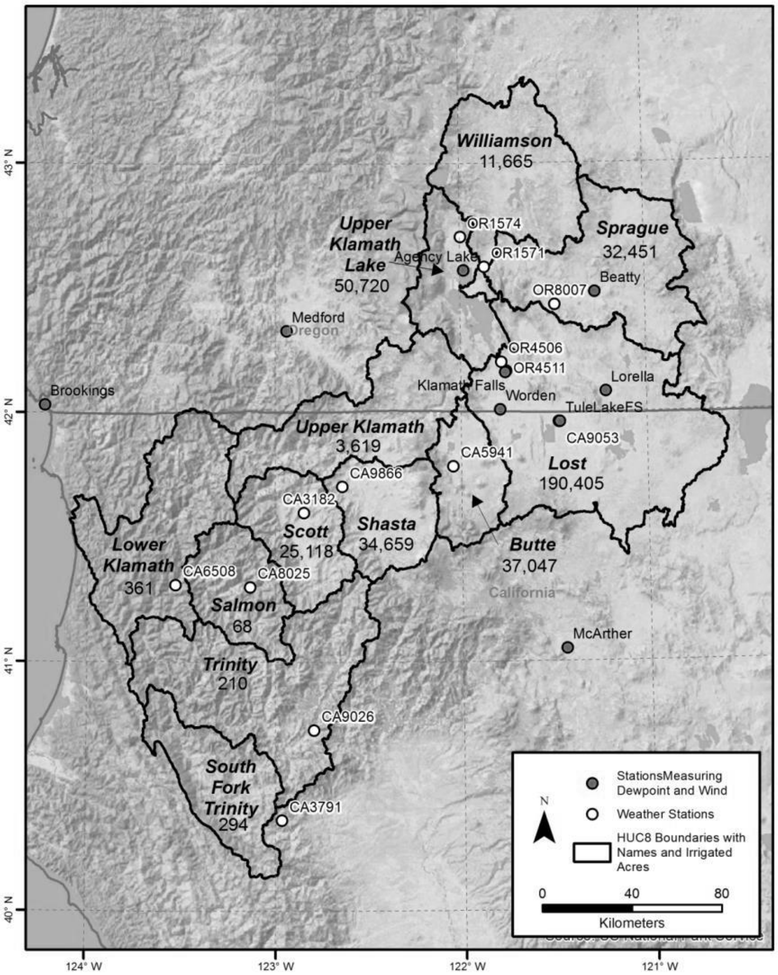


**Figure 4-2. Klamath River Basin – HUC8 Sub-basins, irrigated acres, and weather stations used to simulate baseline and projected irrigation demands**

**Table 4-5. Irrigated land totals and weather stations associated with HUC8 sub-basins**

| HUC8 Name / Number | Weather Station Name(s) | Irrigated Acres |
|---|---|---|
| Williamson / 18010201 | Chiloquin | 11,665 |
| Sprague / 18010202 | Sprague River 2 SE | 32,451 |
| Upper Klamath Lake / 18010203 | Chiloquin NW | 50,720 |
| Lost River / 18010204 | Tule Lake and Klamath Falls | 190,405 |
| Butte /18010205 | Mount Hebron | 37,047 |
| Upper Klamath / 18010206 | Klamath Falls 2 SSW | 3,619 |
| Shasta /18010207 | Yreka | 34,659 |
| Scott / 18010208 | Fort Jones | 25,118 |
| Lower Klamath / 18010209 | Orleans | 361 |
| Salmon / 18010210 | Sawyers Bar | 68 |
| Trinity / 18010211 | Trinity River Hatchery | 210 |
| South Fork Trinity / 18010212 | Harrison Gulch | 294 |
| **Total Irrigated Acres** | | **386,616** |

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI, and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET ($ET_o$) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with previous Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily $ET_o$ for each HUC8 sub-basin as a function of maximum and minimum daily air temperature ($T_{max}$ and $T_{min}$) from the 1950–1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation, and wind speed are empirically estimated as described in Reclamation (2014) per the methods recommended by ASCE (2005). Figure 4-3 shows the spatial distribution of mean daily historical baseline

temperature, precipitation, dewpoint depression,[12] and wind speed (lower right) values used in the model. The historical baseline precipitation and temperature values for each HUC8 sub-basin are included in the model results summary tables provided in Appendix C, Section 1.0. The Figure 4-3 windspeed and dewpoint depression panels include the point locations of weather stations used as the basis for estimating these values for HUC8 sub-basins (see also Figure 4-2 and Appendix C, section 2.0).

Figure 4-3 illustrates warm to cool mean annual temperatures from west-southwest to northeast, respectively, while precipitation varies from moderately high to low amounts from southwest-central to northeast, respectively. The spatial distribution of mean annual dewpoint depression clearly shows northeast areas are more arid while southwest-central areas are more humid. The spatial distribution of mean annual wind speed generally exhibits lower wind speed in west and southwest areas, with higher wind speed in the northeast portion of the basin.

Weighted average soil conditions (including allowable water content and percent clay, silt, and sand) for the irrigated lands in each HUC8 sub-basin were input to the ET Demands model. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-SCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, deep percolation from root zones, antecedent soil moisture condition, and runoff from precipitation.

[12] Dewpoint depression is equal to $T_{min}$ minus dewpoint temperature and is used to estimate vapor pressure or humidity values.
[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

**Deleted:** ¶

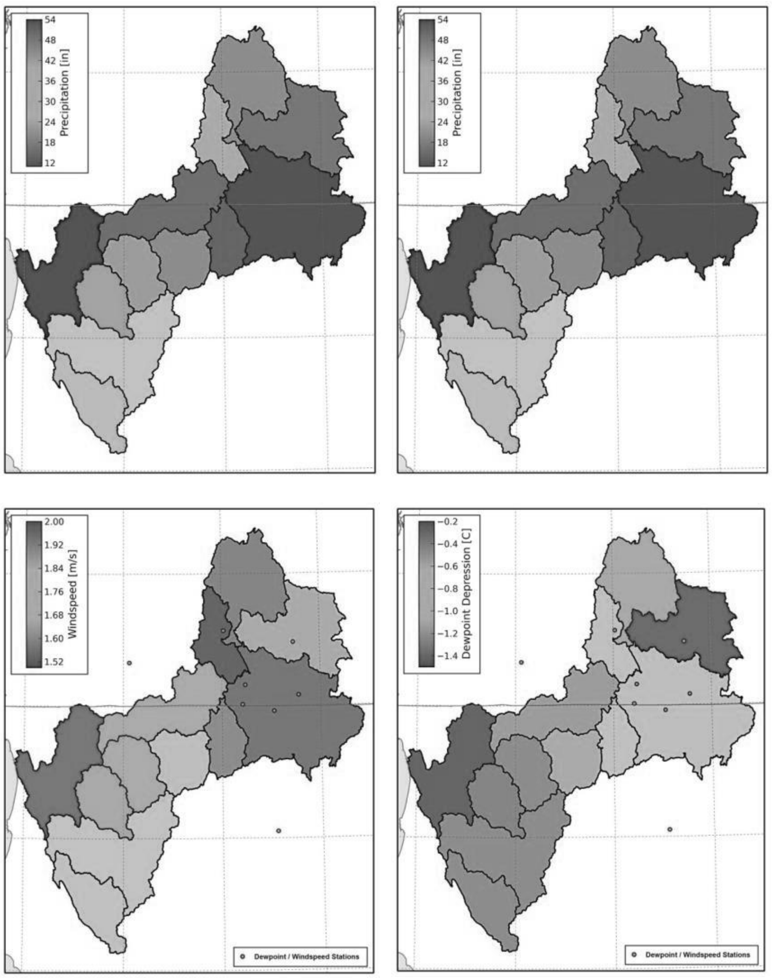


**Figure 4-3. Spatial distribution of historical baseline (1950–1999) mean annual temperature, precipitation, windspeed, and dewpoint depression**

The daily net or actual ET ($ET_c$) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. $ET_c$ for all crop types within a given HUC8 was estimated as follows:

$$ET_c = (K_s K_{cb} + K_e) ET_o$$

where $ET_o$ is the ASCE-PM grass reference ET, $K_{cb}$ is the basal crop coefficient, $K_e$ is the soil water evaporation coefficient, and $K_s$ is the stress coefficient. $K_{cb}$ and $K_e$ are dimensionless and range from 0 to 1.4. Daily $K_{cb}$ values over a season, commonly referred to as the crop coefficient curve, represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. $K_e$ is a function of the soil water balance in the upper 0.1 meter of the soil column, since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. $K_s$ ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate $K_s$. In the case of computing the $ET_c$ and NIWR, $K_s$ is generally 1 but can be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass.

Values of $K_{cb}$ for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in the ET Demands model by each crop specific $K_{cb}$ as a function of air temperature. This is expressed in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of $K_{cb}$ gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the $K_{cb}$ value is generally constant or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the $K_{cb}$ value reduces to simulate senescence. GDD is calculated in the ET Demands model by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in the ET Demands model by factoring in $P_e$ ($NIWR = ET_c - P_e$). $P_e$ is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture, and precipitation runoff. Soil moisture is a function of the moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity[13] and the cumulative soil moisture depletion depth amount.

The NIWR and $ET_c$ rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and $ET_c$ rates, as shown in the equation below.

$$HUC8\ subbasin\ rate\ = \sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$$

The product of the weighted average NIWR and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the $ET_o$, $ET_c$, and NIWR estimates for the entire Klamath River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated. Crop types and corresponding percentages of total crop acreage by HUC8 sub-basin are provided in Appendix C, Section 3.0.

The ET Demands model results for baseline conditions include $ET_o$, $ET_c$, NIWR rate, and NIWR volume for each HUC8 sub-basin. The annual average values for 1950–1999, which represent the historical baseline or current conditions for the purpose of this study, are summarized in Table 4-6. Graphical representations of these values are provided in Figure 4-4. Spatial distributions of $ET_o$, $ET_c$, and NIWR depth ranges from 41 to 51, 29 to 52, and 18 to 37 inches per year, respectively, with higher rates occurring in the northeast portion of the basin where growing season air temperature, solar radiation, and dewpoint depression are significantly larger relative to the southwest-central portion of the basin. NIWR volumes range from 197 AFY in the Salmon HUC8 sub-basin, where there is very little irrigated land, to 329,469 AFY in the Lost River HUC8 sub-basin where the majority of Reclamation's Klamath Project irrigated lands are located.

[13] Field capacity is the amount of water that a well-drained soil should hold against gravitational forces, or the amount of water remaining when downward drainage has markedly decreased (FAO Drainage Paper 56).

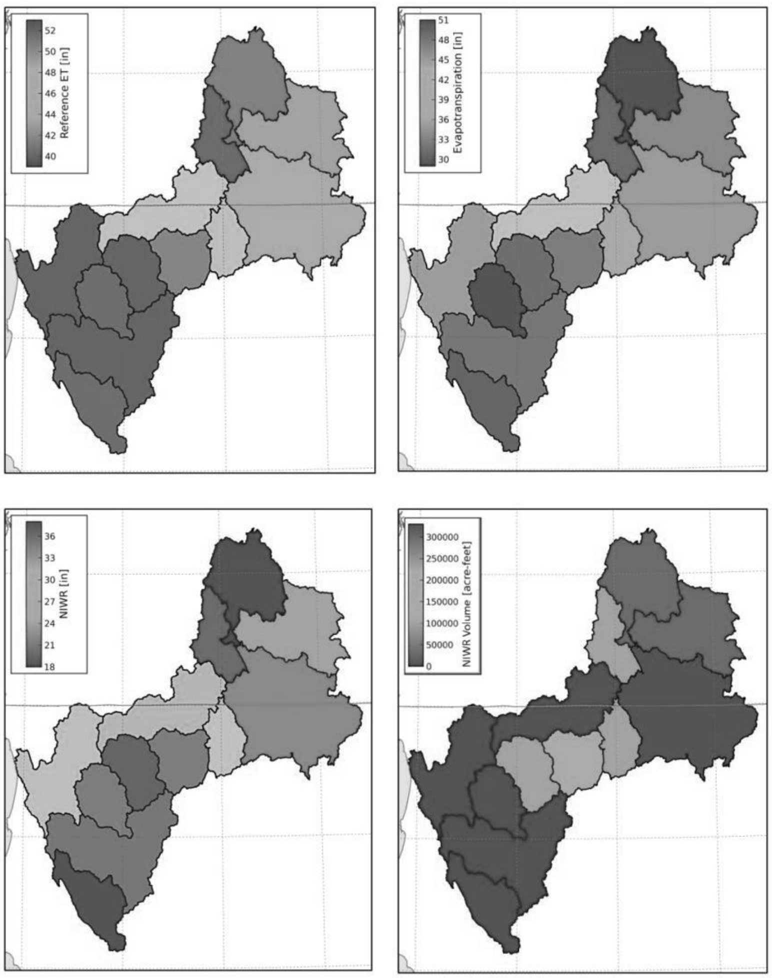


**Figure 4-4. Spatial distribution of baseline reference evapotranspiration, crop evapotranspiration, net irrigation water requirement depth, and NIWR volume**

**Table 4-6. Summary of baseline reference evapotranspiration, crop evapotranspiration, and net irrigation water requirement rates and volumes**

| HUC Sub-basin | $ET_o$ (in/year) | $ET_c$ (in/year) | NIWR Rate (in/year) | NIWR Volume (AFY) |
|---|---|---|---|---|
| Williamson | 40.8 | 29.4 | 18.0 | 17,513 |
| Sprague | 42.3 | 29.5 | 20.4 | 55,216 |
| Upper Klamath Lake | 39.9 | 30.4 | 18.7 | 79,101 |
| Lost River | 43.3 | 34.1 | 20.2 | 329,469 |
| Butte | 46.9 | 36.5 | 27.2 | 83,976 |
| Upper Klamath | 45.4 | 40.9 | 30.7 | 9,255 |
| Shasta | 50.5 | 47.9 | 35.1 | 101,460 |
| Scott | 52.3 | 49.0 | 36.8 | 77,114 |
| Lower Klamath | 52.2 | 44.6 | 29.5 | 887 |
| Salmon | 52.0 | 50.6 | 35.0 | 197 |
| Trinity | 52.3 | 48.6 | 35.9 | 628 |
| South Fork Trinity | 51.8 | 49.6 | 37.4 | 917 |
| **Averages & Total NIWR Vol.** | **47.5** | **40.9** | **28.7** | **755,734** |

Notes: ETo = reference evapotranspiration; ETc = crop evapotranspiration; NIWR = net irrigation water requirement

Table 4-7 provides a summary of the basin total NIWR from Table 4-6 and the previous irrigation estimates by USGS, CDWR, and OWRD. As discussed previously, the USGS and OWRD estimates include conveyance and application losses; the CDWR estimate includes application losses; and the USGS estimate includes irrigation demands for other uses in addition to agricultural irrigation (e.g., golf courses, parks, etc.). Depending on local conditions, significant conveyance and application losses are considered consumptive uses when providing water sources for riparian and wetland plants and sources of evaporation.

The ratio of the basin study estimate (755,734) to the USGS estimate (1,150,318) implies the overall average efficiency of the irrigation systems is approximately 66 percent, which is reasonable. The USGS estimate (1,150,318) is within 5.1 percent of the sum of the QWRD and CDWR estimates (730,000 + 482,504 = 1,212,504).

**Table 4-7. Summary of irrigation demand estimate developed for this study and previous estimates by others**

| Description | Annual Volume (AFY) |
|---|---|
| Basin total crop net irrigation water demand estimated in Klamath River Basin Study | 755,734 |
| Basin total irrigation demand from 2005 USGS Water Use Program | 1,150,318 |
| OWRD 2010 estimate of crop irrigation demand for the Oregon portion of the basin | 730,000 |
| CDWR 2010 estimate of crop irrigation demand for the California portion of the basin | 482,504 |

#### *4.2.1.2 Municipal and Industrial*

This category includes water demands that are met by public water supply systems that range in size from 15 connections[14] to many thousands of connections. The estimates are typically based on the supplier's production quantities, which include water delivered to customers plus leakage and other unaccounted for water. M&I customers include domestic households, industrial facilities, and commercial businesses.

Basin-wide total M&I use, shown in Table 4-3, is 18,204 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, which are entirely within the Klamath River Basin. Modoc, Humboldt, and Del Norte Counties each have small fractions within the Klamath River Basin. Most of the Humboldt and Del Norte County systems serve tribal communities. Note that within the California portion of the basin there is one small M&I system in Modoc County; there are four small systems in Humboldt County, and seven small systems in Del Norte County. Information on these California county systems is discussed later in this section.

Per capita total use estimates for the three counties entirely within the Klamath River Basin were calculated from the USGS data by dividing annual use by the reported population served. These estimates are summarized in Table 4-8.

**Table 4-8. Per capita total M&I water use estimates from USGS 2005 data (including consumptive and non-consumptive portions)**

| County, State | Per Capita Rates (gpcd) |
|---|---|
| Siskiyou , California | 468 |
| Trinity , California | 146 |
| Klamath , Oregon | 188 |

*Source: USGS*

[14] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.

The Siskiyou County per capita total M&I water use reported in 2005 by the USGS is much higher than for Klamath County and Trinity County. Further, review of near current total M&I use from recent planning studies for Weed and Yreka suggest this value to be outside the estimated range for the two largest municipalities in Siskiyou County.

Water plans were reviewed for the four largest municipalities in the Klamath River Basin which include Weed and Yreka in Siskiyou County, California, Weaverville in Trinity County, California, and Klamath Falls in Klamath County, Oregon. Most of the entities that provide M&I service to the smaller municipalities in Del Norte, Humboldt, and Modoc Counties were contacted for recent water use data, as they do not have municipal water plans. These include Willow Creek, Orleans, and Hoopa in Humboldt County, California, Newell in Modoc County, California, and Klamath in Del Norte County, California. Current annual water use for these municipalities is summarized in Table 4-9. Similar to uses identified by municipal water plans, these uses include both consumptive and non-consumptive components.

It should be noted that reported M&I uses typically include both consumptive and non-consumptive components. In the Klamath River Basin Study, those reported M&I uses that include both components are described as total M&I use. This study focuses only on the consumptive portion of M&I use and assumes that 40 percent of total M&I use is consumptive and is used for landscape irrigation, with the remaining 60 percent becoming wastewater effluent. In this section we distinguish between total M&I use and consumptive M&I use, where practicable.

### M&I and Rural Domestic Consumptive Use

Approximately 75 percent of the M&I demand within the Klamath River Basin is from the four largest municipalities (Klamath Falls, OR; Weed, CA; Yreka, CA; Weaverville, CA). Annual rural domestic uses represent approximately 0.4 percent of total basin demand.

Based on Mayer et al. (1999) and given that the majority of the basin's population is located in warmer-drier areas, it appears 40 percent is a reasonable average value for the basin. Mayer et al. (1999) reports the findings of a residential water use study that included 1,188 households in 12 North American cities. The reported range of outdoor use as the percentage of total use is 22 to 67 percent, with a range of 22 to 38 percent for wetter climates. Also, the U.S. Environmental Protection Agency WaterSense Program website[15] reports that one-third of U.S. residential water use is for landscape irrigation.

[15] http://www.epa.gov/WaterSense/pubs/outdoor.html

**Table 4-9. Summary of total M&I use for significant municipalities**

| Location | Annual Use (AFY) | Per Capita Demand (gpcd) | Reference |
|---|---|---|---|
| Klamath Falls, OR (Klamath County) | 9,428 (2010 est) | 167 (1998-2007est) | CDM (2010) |
| Yreka, CA (Siskiyou County) | 2,243 (2010 est) | 280-325 (2011 est) | Pace (2006), Tully and Young (2011) |
| Weed, CA (Siskiyou County) | 994 (2010 est) | NA | Pace (2004) |
| Weaverville, CA (Trinity County) | 841 (2010 est) | NA | Pace (2011) |
| **Total of Above Annual Demands** | **13,506[16]** | | |
| Newell, CA (Modoc County) | 188 | 194 | 2003 CDWR funding application (Hammond Engineering, 2001)[17] |
| Willow Creek, CA (Humboldt County) | 767 | 401 | Personal communication[18] |
| Hoopa, CA (Humboldt County) | 565 | 168 | Personal communication[19] |
| Orleans, CA (Humboldt County) | 153 (OCSD)<br>50 (OMWC) | 319 (OCSD)<br>529 (OMWC) | Personal communication[20] |
| Klamath, CA (Del Norte County) | 166 (est) | 150 (est) | Personal communication[21] |
| **Total of Above Annual Demands** | **1,889** | | |

Comparison of the total for the four large municipalities (13,506 AF) to the USGS reported 2005 M&I total (18,204 AF) indicates approximately 75 percent of the M&I demand within the majority of the basin (Klamath County, Oregon and Trinity and Siskiyou Counties in California) is from these municipalities and the other approximately 25 percent is made up by the smaller M&I systems. The Klamath River Basin Study estimates 2010 total M&I use as the sum of use in

[16] Compare with USGS total demand for Klamath, Siskiyou, and Trinity Counties of 18,204 AFY. The comparison shows that demands from the four major municipalities comprise about 75 percent of the total demand in these three counties.

[17] CDWR funding application reports an annual use of 188 AFY and a 1999 service population of 866. This yields a per capita demand rate of 194 gpcd.

[18] Mr. Lonnie Danel, Administrator (personal communication, November 8, 2013). The 2012 approximate annual use for the Willow Creek Community Service District is 767 AF. Based on the 2010 census population for Willow Creek (1,710) this use yields a per capita demand of 401 gpcd.

[19] According to Mr. Murphy Lott, Operator for Hoopa Public Utilities District, Humboldt County, California (personal communication, November 12, 2013), the 2012 total use for the District's service area was approximately 565 AFY. Based on the reported service area population of approximately 3,000, the per capita average demand is 168 gpcd.

[20] Orleans, California in Humboldt County is served by two public water systems. Debbie Mace of the Orleans Community Service District (OCSD) reports (personal communication, December 5, 2013) approximate annual total M&I usage is 153 AFY serving a population of 430. This equates to a per capita demand of 319 gpcd. Jim Slusser of the Orleans Mutual Water Company (OMWC) reports (personal communication, December 5, 2013) approximate annual total usage is 50 AFY serving a population of 85. This equates to a per capita demand of 529 gpcd.

[21] Ms. Jan Chinook (personal communication, November 12, 2013) with the Klamath, California Chamber of Commerce reports there are seven public water systems serving this community in Del Norte County. The approximate population served by these systems is reported to be 985. Three of seven operators that were successfully contacted reported their systems are not metered. Given the lack of data and the generally transient service population, per capita demand was assumed (150 gpcd) to estimate an annual total M&I use of 166 AFY.

Klamath, Siskiyou, and Trinity Counties, plus uses identified in the small municipalities of Modoc, Humboldt, and Del Norte Counties.

As stated above, an estimated 40 percent of total M&I use is for landscape irrigation. This fraction is considered 100 percent consumptive. The remaining 60 percent of the total M&I use is considered non-consumptive and is assumed to return to receiving waters as wastewater effluent. The computed basin-wide M&I consumptive use of 8,801 AFY is the baseline M&I consumptive use for the Klamath River Basin Study (see Table 4-4). The M&I uses that comprise the Klamath River Basin Study estimate of basin-wide current annual consumptive use are provided in Table 4-10.

**Table 4-10. Summary of total and consumptive M&I uses for the Klamath River Basin Study**

| Location | Annual M&I Use (AFY) |
|---|---|
| Klamath County | 9,736 |
| Siskiyou County | 7,286 |
| Trinity County | 3,093 |
| Small municipalities of Modoc, Humboldt, and Del Norte Counties | 1,889 |
| **Basin Wide Total M&I Use** | 22,004 |
| **Basin Wide Consumptive M&I Use** | 8,801 |

#### *4.2.1.3 Rural Domestic*

The estimate of basin-wide rural domestic use shown in Table 4-3 is 11,255 AFY. The estimate was calculated by summing the USGS Water Use Program values for Klamath, Siskiyou, and Trinity Counties, plus a portion of the reported demand for Modoc County. The Modoc County estimate was calculated as the product of the reported use for the county and the ratio of the estimated population within the basin to the total county population. It is assumed the limited number of rural domestic water users in the portions of the basin in the counties of Del Norte and Humboldt in California and Lake and Jackson in Oregon are negligible. Based on these data and excluding hydropower and lake and reservoir evaporation, annual rural domestic uses represent approximately 0.4 percent of total basin demand. Note that, similar to M&I use, the rural domestic use reported by the USGS includes both consumptive and non-consumptive components. The Klamath River Basin Study assumes that 40 percent of total rural domestic use goes to landscape irrigation and is entirely consumed. (See discussion and references to Mayer et al. (1999) and the WaterSense program[22] above under Section 4.2.1.2, Municipal and Industrial.) The remaining 60 percent of the total rural domestic use is assumed to return to receiving waters via wastewater effluent (i.e., septic systems). This study differentiates between total

[22] http://www.epa.gov/WaterSense/pubs/outdoor.html

rural domestic use, which includes both consumptive and non-consumptive components, and consumptive rural domestic use.

The total rural domestic per capita demands reported by USGS for 2005 range from 106 to 190 gpcd. The 2005 county rates and average for all but Humboldt and Del Norte counties are summarized in Table 4-11. Total rural domestic uses summarized here may be compared with total M&I demands provided in Tables 4-8 and 4-9 in terms of both per capita demands and mean annual total use volumes. Mean annual total rural domestic demands were computed based on the product of per capita demand and estimated population. Generally rural domestic demands are less than M&I demands, except for Trinity County where estimated rural domestic demand rates are higher than M&I. Table 4-9 also provides the estimated baseline consumptive rural domestic use for the Klamath River Basin Study.

**Table 4-11. Summary of 2005 county rural domestic use**

| County | Annual Rural Domestic Use (AFY) | Per Capita Demand (gpcd) |
|---|---|---|
| Siskiyou County, California | 6,621 | 190 |
| Trinity County, California | 1,040 | 158 |
| Klamath County, Oregon | 3,481 | 150 |
| Modoc County, California | 201 | 180 |
| Total Rural Domestic Use | 11,343 | |
| **Consumptive Rural Domestic Use** | **4,537** | |

#### *4.2.1.4 Tribal*

This discussion addresses the consumption portion of water demands associated with the six federally recognized tribes that inhabit the Klamath River Basin: The Klamath Tribes, Quartz Valley Indian Community, Karuk Tribe, Hoopa Valley Tribe, Yurok Tribe, and Resighini Rancheria. Members of these tribes live along different reaches of the Klamath River and in different areas of the basin. Table 4-12 provides a summary of the Klamath basin Native Americans by culture, recognized representative tribal government, and the general location of each tribe in the Klamath basin (taken from Table 1-1, North State Resources, Inc., 2012). The Klamath Tribes live in the Upper Klamath Basin and the other five tribes are in the Lower Klamath Basin.

**Tribal Water Demands**

Tribal trust resources and associated adjudicated and non-adjudicated water rights are described in this section. The needs of fish and wildlife for water are further described in Section 4.2.3.2, Environmental Resources.

Tribal water uses are unique because the associated water rights are considered trust resources.[23] Tribal domestic and industrial water uses are included in the quantification of municipal and industrial demands as well as rural domestic uses summarized above. There are also inter-relationships between tribal water demands and other non-consumptive water use categories (e.g., environmental and ceremonial uses). Critical water-related trust resources associated with instream flow needs and lake levels to support hunting, trapping, gathering, and other cultural practices are briefly described in Section 4.2.3.2, Environmental Resources. However, instream flow uses are incorporated in the Klamath River Basin Study through development of measures which are used to evaluate the impacts of climate change and implementation of adaptation strategies (refer to Chapters 5 and 6).

The federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. The tribes have reserved rights to water according to the Winters Doctrine of 1908. Additionally, the Interior Solicitor's Office stated that "Reclamation is obliged to ensure that project operations not interfere with the Tribes' senior water rights" (Interior, Office of the Solicitor, Pacific Southwest Region, 1995). And, absent a "completed adjudication or other determination of the senior water rights," projects must be "operated on the best available information" (Interior, Office of the Solicitor, Pacific Southwest and Northwest Regions, 1997). The same recognition is extended to other resources such as vegetation and wildlife.

With the exception of the Klamath Tribes, tribal water rights are not officially recognized (adjudicated) by California and Oregon. Oregon's Klamath Basin Adjudication process reached the end of its "administrative" phase in March 2013, and the OWRD reached its Final Order of Determination generally confirming the senior water rights of the Klamath Tribes. In general, tribes' water rights claims seek to assure adequate quantities of good quality water to maintain tribal trust resources including fish, instream flows, groundwater, minerals, and land as well as cultural values, which may be described as traditional religious practices, traditional food preparation, trade and barter of goods, and other practices that reinforce personal and tribal identity (North State Resources, Inc., 2012).

**Table 4-12. Klamath Basin Native American peoples**

| Klamath Basin Native American Cultures | Recognized Representative Tribal Government | General Location of Tribe in the Klamath Basin |
|---|---|---|
| Yurok | Yurok Tribe<br>Resighini Rancheria | Lower Klamath River<br>Lower Klamath River |

[23] Indian trust resources consist of certain real property, natural resources, and related rights, held in trust by the federal government for federally recognized Indian Tribes or individual Indians.

| | | |
|---|---|---|
| Hupa | Hoopa Valley Tribe | Lower Trinity River |
| Karuk | Karuk Tribe<br>Quartz Valley Indian Community | Middle Klamath River<br>Salmon River<br>Scott River |
| Shasta (Wairuhikwaiiruka/Kammatwa) | Quartz Valley Indian Community | Scott River<br>Shasta River<br>Upper Middle Klamath River |
| Modoc | Klamath Tribes | Upper Klamath Basin |
| Klamath | Klamath Tribes | Upper Klamath Basin |
| Snake (Yahooskin) | Klamath Tribes | Upper Klamath Basin |

*Source: North State Resources, 2012*

A portion of the adjudicated and non-adjudicated water rights of the tribes are for agricultural purposes. This consumptive use is addressed by Section 4.2.1.1, Agricultural Irrigation, which identifies the NIWR for existing crops within the basin. These demands are not differentiated between tribal and non-tribal uses.

Primary references for this and additional information related to tribal trust resources include the Klamath Facilities Removal Final Environmental Impact Statement/Environmental Impact Report (Interior and CDFG, 2012), the Trinity Mainstem Fishery Restoration Environmental Impact Statement/Environmental Impact Report (Interior et al., 2000) and the North State Resources, Inc. (2012) report, supporting the Secretarial Determination Overview Report.

#### *4.2.1.5 Livestock*

Livestock water use is included in the USGS Water Use Program estimates. However, because water use by livestock comprises only 0.2 percent of total estimated basin water use and is not likely to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

#### *4.2.1.6 Mining and Commercial/Industrial*

Mining and self-supplied commercial/industrial use is included in the USGS Water Use Program estimates. However, because this consumptive use comprises only 0.2 percent of total estimated basin water use and is not expected to increase substantially in the future, it is not further considered in the Klamath River Basin Study.

### 4.2.2 Other Consumptive Uses and Losses

This section quantifies current losses associated with evaporation at the Klamath River Basin's primary lakes and reservoirs and evapotranspiration by emergent wetlands. Losses result in a reduction of water supply and are therefore included in the assessment of water supply and demand with the intent to quantify current water supply shortages.

#### *4.2.2.1 Wetlands*

This section briefly summarizes the estimation of current wetland ET used for the Klamath River Basin Study, using findings from Stannard et al. (2013). Additional work by Mayer and Thomasson (2004) was used for verification of estimated current wetland ET. Additional work by Bidlake (2002) over the more focused region of Tule Lake NWR was also reviewed in support of estimated wetland.

The Klamath River Basin Study estimates mean annual wetland ET over 341,154 acres of wetlands estimated by the National Wetland Inventory for emergent wetlands.[24] Wetland ET volume is based on work by Stannard et al. (2013), who found that during the average 190-day alfalfa-growing season wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. Estimates of average daily alfalfa and pasture ET were computed by the ET Demands model. For ET Demands model simulations, daily ET for multiple crops was computed for HUC8 sub-basins within the Klamath River Basin, similar to the approach taken by Reclamation (2014) in the West-Wide Climate Risk Assessment. Alfalfa and pasture ET computed by HUC8 sub-basin were used to estimate wetland ET. Use of the ET Demands model for these values, as opposed to alfalfa ET and pasture ET reported by Stannard et al. (2013), allows for direct comparison of the consumptive uses quantified by this study and also allows for evaluation of projected changes in wetland ET in a changing climate. Current mean annual wetland ET, based on estimates of alfalfa and pasture ET using the ET Demands modeling approach described above, is approximately 1,089,061 AFY (averaging wetland ET based on each of alfalfa ET and pasture ET). Estimates of current wetland ET by this study corroborates with the findings of both Stannard et al. (2013) and Mayer and Thomasson (2004), as shown in Table 4-13 in which current wetland ET in units of AFY were computed based on reported ET rates and the same estimated wetland area. This study's estimate of mean annual wetland ET is included in the overall estimate of current water demands provided in Table 4-4. It should be noted that the ET Demands model was not configured to include wetlands ET. However, future research involving the ET Demands model may involve determining model coefficients for wetland vegetation.

[24] http://www.fws.gov/wetlands/

**Table 4-13. Comparison of average annual current wetland ET from available sources**

| Source of Wetland ET Estimate | Average Annual Current Wetland ET (AFY) | ET Rate (ft/yr) |
|---|---|---|
| Mayer and Thomasson (2004) | 1,040,910 | 3.05 |
| Stannard et al. (2013) | 1,049,862 | 3.08 |
| Klamath River Basin Study | 1,089,061[25] | 3.31 |

Mayer and Thomasson (2004) measured and modeled estimates of fall water requirements for the seasonally flooded and permanently flooded wetlands at the Lower Klamath NWR, located in the Lost River HUC8 sub-basin. They found that 60 percent of the total volume of inflow to the wetlands goes to saturate the underlying soils, adding to the water needs of seasonally flooded wetlands. Once the soils are saturated, little loss to infiltration or groundwater seepage in the wetlands would occur. Annual water requirements for both types of wetlands were comparable. Wetlands with 50 percent emergent vegetation and 50 percent open water had an estimated annual ET of 3.05 feet per year over the period 1999–2001. Using the current estimated wetland area of 341,154 acres from the National Wetlands Inventory (USFWS, 2014) for emergent wetlands in the Klamath River Basin along with the above ET rate, the estimated mean annual wetlands ET would be 1,040,910 AFY.

Stannard et al. (2013) sought to improve understanding of ET losses from wetlands by taking ET measurements using the eddy-covariance method from May 2008 through September 2010 at two sites near Upper Klamath Lake. As noted above, they estimated the area of wetlands near Upper Klamath Lake as approximately 70 square kilometers (17,300 acres). From their ET measurements, they found that during the average 190-day alfalfa-growing season, wetland ET is about 7 percent less than alfalfa ET. During the average 195-day pasture-growing season, wetland ET is about 18 percent greater than pasture ET. They also assume alfalfa and pasture ET are equal to wetland ET during the non-growing season. In this study, Stannard et al. estimated a wetland ET rate of approximately 3.08 feet per year. If we extrapolate their computed rate for wetland ET to include the area identified in the National Wetlands Inventory (341,154 acres), their resulting estimate of mean annual wetland ET is 1,049,862 AFY.

[25] Note that the mean ET rate was computed as the mean rate across HUC8 sub-basins, while average annual current wetland ET was calculated as the ET rate multiplied by area, each unique by HUC8 sub-basin, then summed over the entire basin. The average annual current wetland ET is not mathematically equivalent to the mean ET rate multiplied by the basin's 341,154 acres of emergent wetlands. Conversely, the average annual current wetland ET computed using methods by Mayer and Thomasson (2004) and Stannard et al. (2013) was computed as the ET rate multiplied by the total basin area.

#### *4.2.2.2 Lake and Reservoir Evaporation*

The reservoirs evaluated by the study are listed in Table 4-14 along with their capacity and ownership information. Historical evaporation rates (in inches per year) and volumes (in AFY) for these reservoirs have been estimated using an energy balance model, as described below. The historical rates provide the baseline against which future estimates are compared in later sections of this chapter.

**Table 4-14. Klamath River Basin primary reservoirs**

| Reservoir | Storage Capacity (AF) | Maximum Surface Area (acres) | Owner |
|---|---|---|---|
| Clair Engle Lake | 2,448,000 | 17,851 | Reclamation |
| Upper Klamath Lake | 629,780 | 90,000 | Reclamation |
| Clear Lake | 513,330 | 25,760 | Reclamation |
| Gerber Reservoir | 104,460 | 4,000 | Reclamation |
| Tule Lake | 60,592 | 13,074 | Reclamation |
| COPCO 1 Reservoir | 46,867 | 1,000 | PacifiCorp |
| Iron Gate Reservoir | 58,794 | 944 | PacifiCorp |
| John C. Boyle Reservoir | 3,495 | 420 | PacifiCorp |

*Source: PacifiCorp (2004c)*

The estimated evaporation rates for the Reclamation reservoirs in the basin were calculated using the complementary relationship lake evaporation (CRLE) model (Morton et al., 1985). CRLE is an open water evaporation model that accounts for water temperature, albedo, emissivity, and heat storage effects to estimates of monthly evaporation. Reclamation collaborated with the DRI (Reno, Nevada) in the development and application of the model for this study.

The collaborative reservoir evaporation modeling effort with DRI was initiated as part of the WWCRA. Under the WWCRA work, Upper Klamath Lake evaporation was modeled along with 11 other reservoirs in the western U.S.

The WWCRA Water Demands Report (Reclamation, 2015) provides a detailed description of the CRLE model and its application for Upper Klamath Lake. The model parameters for Upper Klamath Lake developed under the WWCRA were directly applied for simulation of open water evaporation in Upper Klamath Lake in this study. The other reservoirs listed in Table 4-14 were also modeled using the same approach.

The CRLE model calculates estimated evaporation for historical average reservoir conditions. Average monthly historical reservoir conditions (storage volume and surface area) were calculated using historical data and assumed constant for the analysis period (1950–1999). The same air temperature-based relationship used for estimating solar radiation for Upper Klamath Lake, based on Klamath Falls

Agrimet weather station data, was applied for modeling evaporation at the other reservoirs. Relationships for estimation of dewpoint depression (humidity) were developed based on historical data from the weather stations, discussed above in Section 4.2.1.1, Agricultural Irrigation, and as shown in Figure 4-2.

Table 4-15 includes a summary of the CRLE model results for the historical baseline period (1950–1999), including average annual evaporation rates and net evaporation (evaporation minus precipitation) rates for each reservoir. Table 4-15 also includes evaporation and net evaporation volume estimates based on the model results and historical average reservoir conditions. Note that historical average reservoir conditions differ from the maximum conditions reported in Table 4-14.

**Table 4-15. Klamath River Basin reservoirs evaporation model results summary for 1950 to 1999 historical baseline period**

| Reservoir | Evaporation (inches/year) | Evaporation (AFY)[26] | Net Evaporation (inches/year) | Net Evaporation (AFY)[11] |
|---|---|---|---|---|
| Clair Engle Lake | 45.0 | 49,152 | -26.0 | -28,412 |
| Upper Klamath Lake | 44.0 | 263,483 | 21.1 | 125,977 |
| Clear Lake | 45.6 | 81,711 | 32.0 | 57,300 |
| Gerber Reservoir | 44.4 | 8,947 | 24.1 | 4,862 |
| Tule Lake | 45.2 | 23,723 | 33.3 | 17,484 |
| COPCO 1 Reservoir | 43.9 | 3,427 | 20.8 | 1,626 |
| Iron Gate Reservoir | 44.8 | 3,446 | 27.2 | 2,089 |
| J.C. Boyle Reservoir | 44.2 | 729 | 22.5 | 371 |

Stannard et al. (2013) conducted an open water and wetland evaporation study for Upper Klamath Lake, Oregon. Bowen ratio energy balance was utilized to estimate open water evaporation during the summer and fall of 2008 and the growing seasons of 2009 and 2010. To evaluate the skill of CRLE application in the Klamath River Basin, the CRLE model was forced with measured solar radiation, air temperature, and dewpoint temperature obtained from the Klamath Falls Agrimet station for the 2008–2010 study period of Stannard et al. (2013). Results of the seasonal comparison are favorable, with daily average evaporation rates for this study of 0.20 inches per day compared to 0.21 inches per day by Stannard et al. (2013).

[26] Reservoir evaporation and net evaporation volumes were computed using mean monthly surface area over the simulation period.[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

Deleted: ¶

#### *4.2.2.3 Operational Inefficiencies*

Operational inefficiencies such as canal seepage and on-farm losses associated with irrigation methods are not explicitly quantified in the Klamath River Basin Study. The largest irrigated region in the watershed is Reclamation's Klamath Project. Within the Project area, on-farm runoff and canal spills are captured in drains and reused such that the overall efficiency of the Project is considered to be relatively high. This is based on water budgets developed as part of previous studies (Davids, 1998; Freeman and Burt, undated; Reclamation, 2007b). For other irrigated regions, such as the Shasta and Scott Valleys, this study assumes that non-beneficial consumptive use of conveyance and on-farm losses is not a significant portion of the overall losses in the watershed. The USGS Water Use Program estimates for agricultural irrigation use include crop demands, conveyance losses, and on-farm losses.

#### *4.2.2.4 Phreatophyte Vegetation*

Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are included in the water budget through the natural flow computations (refer to Chapter 3) and therefore are not shown separately as losses. Needs of other vegetation for water are also included in the water budget. For example, BLM and USFS conservation initiatives associated with the 1994 Northwest Forest Plan preserve old growth vegetation and riparian buffers throughout the Southern Oregon / Northern California Coast Evolutionary Significant Unit and range of the Northern Spotted Owl (BLM and USFS, 2005).

### 4.2.3 Non-Consumptive Uses

Non-consumptive uses are those which do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.), water needs to support fish and wildlife, and hydropower production, among others. In one sense, these uses may be considered demands in that certain water levels or flows are required to support them. However, because these uses do not result in a loss of water in a planning context, the Klamath River Basin Study addresses them in terms of measures of system reliability. The measures are used to evaluate how well the available water supply is able to meet various needs in the watershed.

> **Non-Consumptive Uses**
>
> Non-consumptive uses include recreation, environmental resources, hydropower, and aquaculture. Because non-consumptive uses do not result in a reduction of available water supply, they are addressed in Chapter 5, System Reliability as measures for evaluating the impacts of climate change and implementation of adaptation strategies.

This section briefly describes the identified non-consumptive uses in the Klamath River Basin. However, details of water requirements and/or needs to sustain these uses are further quantified in Chapter 5, System Risk and Reliability Analysis.

#### *4.2.3.1 Recreation*

The expansive rural landscape of the Klamath River Basin offers a myriad of outdoor recreational opportunities, many of which are either directly or indirectly associated with the basin's water resources. Rivers, streams, and lakes are common throughout the basin's mountainous landscape, and reservoirs and wetlands exist in the valleys and high plateau areas of the central and eastern portions of the basin. The basin's rivers, streams, lakes, reservoirs, and wetlands provide a variety of recreational opportunities including camping, sightseeing, hunting, fishing, boating, hiking, and wildlife viewing.

There are five national forests within the basin (Klamath, Fremont, Winema, Six Rivers, and Modoc), a joint national and State park (Redwood), a national park (Crater Lake), two national monuments (Lava Beds and Cascade-Siskiyou) and five national wildlife refuges that make up the Klamath Basin NWR Complex (Klamath Marsh, Tule Lake, Clear Lake, Upper Klamath, and Lower Klamath). Recreation opportunities in these forests, parks, and refuges include camping, hiking, snowmobiling, sightseeing, wildlife viewing, hunting, and fishing.

Large sections of the Klamath River and its tributaries are designated as national wild and scenic rivers (WSR) under the Wild and Scenic Rivers Act, including segments of the Klamath, Scott, and Salmon Rivers and Wooley Creek totaling 297 miles. Extensive public and private recreational opportunities exist along the Klamath River and its tributaries.

The Klamath River Basin Study focuses on flow-related recreational uses, as they are more directly associated with water supply than other recreational demands such as camping and sightseeing, for example. The recreational uses considered in this study are fishing and boating in the Klamath and Trinity Rivers. Chapter 5, System Reliability quantifies optimal flow ranges for these activities, as reported by the Klamath Facilities Removal EIS/EIR (Interior and CDFG, 2012).

The modeling framework of the Klamath River Basin Study does not allow for evaluation of impacts of climate change on natural unmanaged lakes within the watershed; however, evaluation of reservoir levels is part of the system reliability analysis in Chapter 5.

#### *4.2.3.2 Environmental Resources*

Numerous fish species use the Klamath Basin during all or some portion of their lives. Native species include salmonids, lamprey, sturgeon, suckers, minnows, and sculpin. Many other species are present in the Klamath River estuary. Salmonids in the Klamath River include fall and spring Chinook salmon; coho salmon; fall-, winter-, and summer-run steelhead; and coastal cutthroat trout. The salmonids share many similar life-history traits, but the timing of their upstream

migrations, habitat preferences, and distributions differ (Interior and CDFG, 2012). A number of non-native species have also been introduced into the watershed including yellow perch, largemouth bass, spotted bass, sunfish, and catfish. These species all have unique needs for Klamath River water which must be considered in conjunction with management practices for human uses.

**Water Quality**
Water quality in the Klamath River Basin is affected by both natural and human influences. The volcanic terrain supports soils that are naturally high in phosphorus. Human influences including development, wetland draining, agriculture, ranching, logging, and water management have altered streamflows and water temperatures and increased nutrient and sediment loading in the river system. In addition, mining activities, dam construction, and management for hydropower in the Lower Klamath Basin have further affected river conditions (Interior and CDFG, 2012). As a result of natural and human activities, water quality standards in the Upper Klamath Basin have not been met for many years (Stillwater Sciences, 2013). Table 4-16 summarizes the water quality impaired water bodies in the Klamath River Basin as identified by the Klamath Facilities Removal EIS/EIR (Table 3.2-8 in Interior and CDFG, 2012). The identified water quality impairments impact the beneficial uses of the Klamath River designated by the Klamath Facilities Removal EIS/EIR, which are categorized as Aesthetic and Cultural, Agricultural Water Supply, Commercial, Fish and Wildlife, Potable Water Supply, Industrial Water Supply, and Navigation.[27] For example, known and/or perceived concerns over health risks associated with seasonal algal toxins have resulted in the alteration of traditional cultural tribal practices such as gathering and preparation of basket materials and plants, fishing, ceremonial bathing, and ingestion of river water.

[27] The Staff Report for the Klamath River TMDLs, the Klamath River Site Specific Dissolved Oxygen Objective, and the Klamath and Lost River Implementation Plans (NCWQCB, 2010b) lists 28 beneficial uses, 17 of which were found to be impaired including: Native American culture; subsistence fishing; cold freshwater habitat; warm freshwater habitat; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and/or early development; water contact recreation; non-contact water recreation; M&I supply; shellfish harvesting; estuary habitat; marine habitat; aquaculture; agricultural supply; commercial and sport fishing; and wildlife habitat.

**Table 4-16. Water quality impaired water bodies within the area of analysis[1]**

| Water Body Name | Water Temperature | Sedimentation | pH | Organic Enrichment/Low Dissolved Oxygen | Nutrients | Ammonia | Chlorophyll-a | Microcystin |
|---|---|---|---|---|---|---|---|---|
| **Oregon[2]** | | | | | | | | |
| Sprague River and tributaries | $X^{S}$ | | $X^{S}$ | $X^{S}$ | | | | |
| Williamson River and tributaries | X | | | | | | | |
| Upper Klamath Lake and Agency Lake | | | X | X | | | X | |
| Upper Klamath River (Keno Dam to Link River Dam, including Keno Impoundment/Lake Ewauna) | | | $X^{S}$ | $X^{SP,S,F,W\ (3)}$ | | $X^{SP,S,F,W}$ | $X^{S}$ | |
| Upper Klamath River Oregon-California state line to Keno Dam (including J.C. Boyle Reservoir) (4) | $X^{SP,S,F,S\ (5)}$ | | | $X^{SP,S,F,W\ (3)}$ | | | | |
| **California** | | | | | | | | |
| Lower Lost River (Tule Lake, Lower Klamath Lake National Wildlife Refuge, and Mt. Dome) | | | X | | X | | | |
| Middle Klamath River Oregon-California state line to Iron Gate Dam (including COPCO Lake Reservoir [1 and 2] and Iron Gate Reservoir) | X | | | X | | | | X |
| Middle Klamath River Iron Gate Dam to Scott River Reach 6 | X | | | X | X | | | X |
| Shasta River | X | | | X | | | | |
| Scott River | X | X | | | | | | |
| Salmon River | X | | | | | | | |
| Middle and Lower Klamath River Scott River to Trinity River Reach 7 | X | | | X | X | | | X |
| Lower Klamath River-Trinity River to Mouth | X | X | | X | X | | | |

*Source: Table 3.2-8 in Interior and CDFG, 2012*

Notes:

1 While there are additional water quality impaired waterbodies in the area of analysis, the waterbodies listed in this table are the ones that are directly relevant to the water quality analysis for this Klamath Facilities Removal EIS/EIR.

2 Oregon lists specific reaches of the Klamath River by river mile and includes specific seasons, in some cases (Kirk et al., 2010).

3 Listed for dissolved oxygen only (non-spawning) (Kirk et al., 2010).

4 Oregon defines particular river miles for their listings.

5 Non-spawning (Kirk et al., 2010).

6 Selected minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include Beaver Creek, Cow Creek, Deer Creek, Hungry Creek, and West Fork Beaver Creek (USEPA, 2010a).

7 Minor tributaries to the Middle and Lower Klamath River that are impaired for sediment and sedimentation include China Creek, Fort Goff Creek, Grider Creek, Portuguese Creek, Thompson Creek, and Walker Creek (USEPA, 2010a).

Key:

Sp = Listed for spring season
S = Listed for summer season
F = Listed for fall season
W = Listed for winter season

Effects on regional water quality have resulted in multiple federal, state, and tribal programs and planning documents to regulate and protect water quality in the area of the Klamath River Basin. For example, the states of Oregon and California have established and obtained EPA approval of water quality standards (referred to as "water quality objectives" in California) for waters in the Klamath River Basin, including designated beneficial uses (PacifiCorp, 2004b; Interior and CDFG, 2012). Also, several of the Klamath River Basin native tribes have adopted their own water quality objectives for portions of the Klamath and Trinity Rivers. Water quality objectives adopted by the Hoopa Valley Tribe establish water quality objectives for those portions of the Trinity and Klamath Rivers under the jurisdiction of the tribe. The Yurok and Karuk Tribes have also adopted water quality objectives, as has the Resighini Rancheria; however, the associated water quality plans have not yet been approved by USEPA (NCRWQCB, 2010b).

For water bodies included on the Clean Water Act Section 303(d) list of impaired water bodies, the state with jurisdiction over the water body must develop TMDLs to protect and restore beneficial uses of water. TMDLs set limits on the amount of pollutants that can be added to a water body while still protecting identified beneficial uses. TMDLs have been established for various parts of the Klamath River Basin since about 2001. The status and pollutants regulated under Klamath River Basin TMDLs are summarized in Table 3.2-9 of the Klamath Facilities Removal Final EIS/EIR (Interior and CDFG, 2012).

Water levels and flow rates are inherently related to water quality in the Klamath River Basin. The need for improved water quality by environmental resources may be considered a demand, in one sense, because threshold flows are needed to sustain a healthy river system. However, because these needs are non-consumptive, the Klamath River Basin Study incorporates water quality criteria and associated TMDLs in the analysis of system reliability. Specifically, environmental health of the watershed is assessed through analysis of water temperature as a surrogate for overall watershed ecological health. Water quality criteria and TMDLs for stream temperature are incorporated as measures for evaluation of system reliability in Chapter 5.

**Instream Flow Targets**

Instream flow targets have been established for parts of the Klamath River Basin both through state codes, state and federal regulatory requirements, and cooperative agreements such as Reclamation's 2013 Biological Assessment for Proposed Klamath Project Operations and the associated 2013 non-jeopardy [28] Biological Opinion issued by the NMFS and USFWS. Instream flow targets are one means of working toward the maintenance and even recovery of threatened and endangered species in the basin. However, recommended instream flows are highly uncertain due to limited data availability and our limited understanding of

[28] An ESA Section 7 non-jeopardy Biological Opinion is one where USFWS or NMRS determines that a federal action is not likely to jeopardize the existence of a listed species or result in the destruction or adverse modification of critical habitat.

all of the direct and indirect effects of the environment on the species it supports. As we learn more about species recovery in responses to instream flow actions, these recommendations are likely to evolve through time.

Instream flow recommendations exist for reaches of the Klamath River (Reclamation, 2012d; NMFS and USFWS, 2013; Interior and CDFG, 2012; Hardy et al., 2006) as well as the tributaries of the Shasta River (McBain and Trush, 2014) and Trinity River (Interior, 2000). In addition, the federal government, as a trustee, has an affirmative obligation to manage tribal rights and resources for the benefit of the tribes. Interior supports Winters Doctrine rights which entitle tribes in the Klamath River Basin to sufficient water to support fishing and harvesting and cultural practices. Also, recognition of tribal reserved fishing rights is consistent with the federal precedent set in United States v. Adair (Interior and CDFG, 2012). Although the Klamath River Basin tribes have reserved rights to support their livelihoods, for the most part instream flow needs to support those activities have not been quantified, with the exception of the Klamath Tribes as part of Oregon's Klamath Basin adjudication process.

Similar to other non-consumptive water uses, recommended instream flow targets may be considered a demand in that certain flows are required to sustain fish species and support other uses. However, since these uses do not result in a reduction of water supply, they are incorporated in the analysis of system reliability in Chapter 5. Namely, instream flow targets may be used as measures in the evaluation of impacts of climate change on the watershed with and without implemented adaptation strategies. Details of recommended instream flow targets are included in Chapter 5.

**Wildlife Refuge Water Targets**

Klamath Basin National Wildlife Refuges is a complex of six refuges: Lower Klamath, Tule Lake, and Clear Lake in northern California and Bear Valley, Upper Klamath, and Klamath Forest Refuges in southern Oregon. All of the complex refuges are adjacent to or within Reclamation's Klamath Project with the exception of Bear Valley, which was established in 1978 and consists of old growth pine forest to protect a major night roost site for wintering bald eagles in Southern Oregon. The USFWS manages the refuges under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System (Reclamation, 2012d). They were established by various executive orders starting in 1908, and support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. Each year these refuges serve as an annual stopover for approximately three-quarters of the flyway waterfowl with peak concentrations of over one million birds. Reclamation manages leases on refuge lands for agricultural purposes through a cooperative agreement with the USFWS (Reclamation, 2012d).

The refuges (with the exception of Bear Valley and Clear Lake) have federally-reserved water right claims for the water necessary to satisfy the refuges' primary purposes subject to more senior water rights in the basin, including the Klamath Tribes and Reclamation's Klamath Project. The 2013 BA for Klamath Project operations outlines the availability of water to the Lower Klamath and Tule Lake NWRs (Reclamation, 2012d). In addition, Risley and Gannett (2006) estimated water needs of the Lower Klamath and Tule Lake NWRs using evapotranspiration estimates, with different rates for each of four land-use categories. With the exception of open water evaporation and wetland ET, water used by refuges is generally non-consumptive. Recommended targets, like those summarized by the above sources, are provided in Chapter 5, System Reliability and incorporated as measures for evaluation of system reliability.

#### *4.2.3.3 Hydropower*

The Klamath River Basin has nine major hydropower generating facilities, seven in the Upper Klamath Basin and two in the Trinity River sub-basin. Other small hydropower generating facilities in the basin include the C Drop Plant on Reclamation's Klamath Project and two small hydropower facilities in Siskiyou County. The seven major hydropower plants in the Upper Klamath Basin are owned and operated by PacifiCorp of Portland, Oregon. The PacifiCorp facilities are regulated by the Federal Energy Regulatory Commission (FERC) as Project No. 2082 and are operating under annual licenses since the expiration of the original license in March 2006. Future operations are dependent on the resolution of the relicensing proceedings for these facilities, which may be addressed through either issuance of a new project license by FERC or the passage of federal legislation enacting the Klamath Hydroelectric Settlement Agreement (KHSA) and related Klamath settlements, which provide for the potential removal of these facilities.

Since 1992, operations of PacifiCorp's facilities have been adjusted to protect ESA-listed threatened species. These adjustments were made to address then-current minimum levels in Upper Klamath Lake and minimum instream flows in the Link River and in the Klamath River below Iron Gate dam described in biological opinions for Reclamation's Klamath Project (PacifiCorp, 2004b). The current river flow and Upper Klamath Lake level requirements are described in the 2013 Joint Biological Opinion for Klamath Project Operations by the USFWS and NMFS (NMFS and USFWS, 2013). If PacifiCorp's hydroelectric dams are removed as part of the KBRA/KHSA, the hydroelectric water rights at all of PacifiCorp's Klamath facilities (except Fall Creek) in Oregon will be dedicated or assigned to instream water rights and administered by the ODFW, while those in California will be abandoned, according to Section 7.6.5 of the KHSA.

The other two major hydropower generating facilities are located in the Trinity River sub-basin. The Lewiston powerplant provides power to the adjacent Trinity River Fish Hatchery and additional energy is sold. Trinity Power plant is a peaking plant associated with the Trinity River Diversion for Reclamation's Central Valley Project. Flow rates and associated power production at both

facilities are subject to the Trinity River Restoration Program Record of Decision (Interior, 2000).

The Klamath River Basin Study provides the basis for evaluations of changes in future hydrologic conditions and resulting changes in power generation capacity and timing. The analysis of system reliability (refer to Chapter 5) allows for quantification of projected turbine releases and hydropower production as a result of climate change and implemented adaptation strategies. This study does not evaluate projected changes in the demand for hydropower in a changing climate. Water rights and instream flow requirements associated with hydropower production are utilized in the system reliability analysis as measures for evaluation of changes in power production associated with various managed flow conditions in a changing climate.

#### *4.2.3.4 Aquaculture*

Another non-consumptive use of water within the Klamath River Basin includes aquaculture, which is defined as the rearing of aquatic animals. This use is quantified by the USGS Water Use Program; however, the percentage of total basin water use is only 3 percent. Due to the small percentage of overall water use, the fact that this use is largely non-consumptive, and the lack of information as to the impacts of climate change on aquaculture, this use is not further considered in the Klamath River Basin Study.

## 4.3 Effects of Climate Variability and Change on Demand

### 4.3.1 Climate Change Scenarios

The Klamath River Basin Study primarily utilizes climate change scenarios that are derived using an ensemble informed hybrid delta (HDe) method approach (Hamlet et al., 2013; Reclamation, 2010b; Reclamation, 2011d). The scenarios are derived from both CMIP3 and CMIP5 bias corrected and spatially downscaled (BCSD) GCM climate projections, as these are considered equally likely potential climate futures at this time. The approach allows a high number of CMIP3 and CMIP5 climate projections to be distilled into a small number of representative climate change scenarios. The same scenarios used for evaluation of future water supply are used in this chapter's estimation of demands to meet consumptive uses, namely M&I and rural domestic as well as losses due to reservoir evaporation. Development of future agricultural scenarios involved using similar climate change scenarios, but with prior adjustments made to the underlying BCSD climate projections to account for biases in projected versus observed weather over irrigated areas (for more information, refer to WWCRA Demands Assessment, Reclamation, 2015).

Development of climate change scenarios is described in Section 3.5.1.2, Deriving Climate Change Scenarios from Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in

this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). Five scenario types are derived from the large number of CMIP3 and CMIP5 BCSD climate projections: warm-wet (WW), warm-dry (WD), central-tendency (CT), hot-wet (HW), and hot-dry (HD). Discussions of how the temperature and precipitation projections for the five HDe scenarios are used to estimate the various future demands are provided in the following sections.

### 4.3.2 Growth Scenarios

Future water demand with respect to consumptive uses and evaporation losses may have a number of driving forces aside from those directly related to climate, including demographics, land use, technological development, and socioeconomics. Because it is highly uncertain how these driving forces may unfold in the future, we employ a scenario-based approach to projected growth.

To evaluate the impacts of climate change on system performance of existing and anticipated water infrastructure and operations in the Klamath River Basin, a baseline condition is established. In typical long term planning studies, this baseline condition may be called the Future No Action alternative. A Future No Action alternative incorporates climate change scenarios and requires that assumptions be made regarding future growth in the watershed. The Future No Action alternative in the Klamath River Basin Study corresponds with one future growth scenario and ten climate change scenarios (five CMIP3-based scenarios and five CMIP5-based scenarios), each for the 2030s and 2070s, for a total of twenty future scenarios.

In general, the growth scenario encompasses projected population growth, where reported by the states and municipalities, and current agricultural practices. A brief description of the growth scenario is provided in this section. Assumptions regarding the future growth scenario are summarized below and in Table 4-17. Additional details regarding the growth scenario are provided in Section 4.3.3 which quantify the impacts of climate change on water demands.

As shown in Table 4-17, this study assumes that cropping patterns and number of irrigated acres are static in quantifying future agricultural irrigation demands. Altered cropping patterns may be considered in this study as implemented adaptation strategies in the analysis of system reliability. For M&I and rural domestic uses, a defined percentage of the water use is landscape irrigation and this is also considered static. Population estimates that define the total M&I and rural domestic future water usage are based on two primary sources. If population projections are provided by individual municipal water plans, those projections are incorporated into the demand scenario. For regions where municipal water plans may not exist, and for rural domestic water use, historical population trends are extrapolated into the future and incorporated in the demand scenario. For losses due to reservoir or lake evaporation, it is assumed that historical average reservoir levels exist in the future. Alternative future reservoir levels are considered as implemented adaptation strategies in the analysis of system reliability. Finally, for future wetland ET estimates, it is assumed that the current

number of wetland acres (based on the current National Wetland Inventory) is static.

**Table 4-17. Summary of assumptions for Klamath River Basin Study future growth scenario**

| Consumptive Use or Loss | Element | Assumptions for Future Scenarios |
|---|---|---|
| Agricultural irrigation | | |
| | Cropping patterns | Static, based on historical |
| | Irrigated acres | Static, based on historical |
| M&I and rural domestic | Landscape irrigation = 40 percent of total use | Static, based on historical |
| | Population growth | Based on water plans or extrapolations of historical trends (if projections not available) |
| Lake and reservoir evaporation | Average lake and reservoir levels | Static, based on historical |
| Wetlands ET | Wetland acres | Static, based on historical |

### 4.3.3 Projected Future Water Demands

Numerous factors were considered in the estimation of the basin's future water demands. The primary factors include population growth, agricultural practices, and climate change. Population growth, agricultural practices, and other socioeconomic conditions are incorporated in the demand scenario described above. Projections of climate change are incorporated separately, such that there are five HDe climate scenarios for each of the CMIP3- and CMIP5-based projections and for each future time horizon (2030s and 2070s). Each of these climate change scenarios is paired with the single demand scenario considered in this study.

As discussed previously, rigorous quantitative analyses were performed to estimate the demands to meet predominant consumptive uses in the watershed: agricultural irrigation, M&I, rural domestic, wetlands, and losses due to reservoir evaporation. The implications of climate change on non-consumptive uses are evaluated as part of Chapter 5, System Reliability Analysis.

Table 4-18 summarizes the projected changes in basin-wide consumptive use (both human influenced and natural) for the predominant use categories: agricultural irrigation, M&I, rural domestic, and losses due to reservoir evaporation and wetland ET. Projected changes are presented for all five HDe climate change scenarios for each of the CMIP3- and CMIP5-based projections, as well as for two future time horizons, the 2030s and 2070s.

**Table 4-18. Summary of basin-wide projected changes in consumptive water use and losses**

| Scenario | Period | BCSD Projection | Total (AFY) | Total Percent Change |
|---|---|---|---|---|
| Historical | Historical | - | 2,039,430 | - |
| Warm Dry | 2030 | CMIP-3 | 2,233,781 | 10% |
| Warm Dry | 2030 | CMIP-5 | 2,277,042 | 12% |
| Warm Wet | 2030 | CMIP-3 | 2,190,454 | 7% |
| Warm Wet | 2030 | CMIP-5 | 2,225,238 | 9% |
| Hot Dry | 2030 | CMIP-3 | 2,387,983 | 17% |
| Hot Dry | 2030 | CMIP-5 | 2,405,865 | 18% |
| Hot Wet | 2030 | CMIP-3 | 2,313,274 | 13% |
| Hot Wet | 2030 | CMIP-5 | 2,349,212 | 15% |
| Central Tendency | 2030 | CMIP-3 | 2,284,936 | 12% |
| Central Tendency | 2030 | CMIP-5 | 2,304,374 | 13% |
| Warm Dry | 2070 | CMIP-3 | 2,380,969 | 17% |
| Warm Dry | 2070 | CMIP-5 | 2,324,159 | 14% |
| Warm Wet | 2070 | CMIP-3 | 2,308,778 | 13% |
| Warm Wet | 2070 | CMIP-5 | 2,266,970 | 11% |
| Hot Dry | 2070 | CMIP-3 | 2,528,603 | 24% |
| Hot Dry | 2070 | CMIP-5 | 2,568,869 | 26% |
| Hot Wet | 2070 | CMIP-3 | 2,428,364 | 19% |
| Hot Wet | 2070 | CMIP-5 | 2,501,320 | 23% |
| Central Tendency | 2070 | CMIP-3 | 2,393,777 | 17% |
| Central Tendency | 2070 | CMIP-5 | 2,406,350 | 18% |

Similarly, for all future climate scenarios Figure 4-5 summarizes projected changes for each type of consumptive use or loss considered in the Klamath River Basin Study for the 2030s and 2070s.

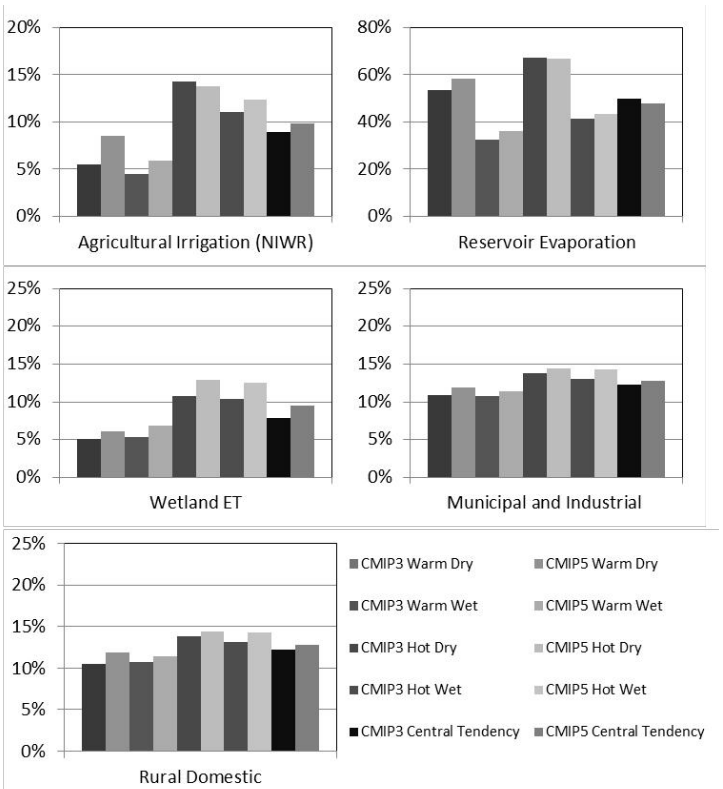


**Figure 4-5. Summary of basin-wide projected changes in consumptive water use and losses for the 2030s by use type**

#### *4.3.3.1 Human Influenced Consumptive Uses*

Projected consumptive uses to meet future demands are summarized in this section, incorporating projected HDe climate scenarios for two future time horizons, the 2030s and the 2070s, and a single future growth scenario. Descriptions of the approaches used to incorporate climate change scenarios and growth scenarios are provided in the respective subsections below on various consumptive uses and losses.

**Agricultural Irrigation**

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described in Section 4.2, Current Demand was implemented using the approach described in Reclamation (2015). Any differences in the approach details are discussed below.

For example, the Klamath River Basin Study utilizes two future time periods for analysis of climate change impacts (2030s and 2070s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA. Also, there are slight differences in the projection ensemble selection process for development of HDe scenarios. This study utilizes a subset of 10 climate projections to inform each of the five climate scenarios, while the WWCRA utilizes the full set of climate projections. Further discussion of the approach for climate change scenario development for this study is provided in Chapter 3. Another difference in approach for assessing agricultural irrigation demands is the use of both CMIP3 and CMIP5 projections in this study; the WWCRA uses solely CMIP3 projections. At the time the WWCRA work began, CMIP5 projections were not readily available.

As mentioned above, a single growth scenario was used in conjunction with multiple future climate scenarios to encompass a range of potential future consumptive water demands. Collectively these scenarios comprise the Future No Action scenario. This alternative generally includes historical cropping patterns and irrigated acreage. Additional approach details for assessment of future agricultural irrigation demands are provided in this section. In the discussion of Current Water Demands, the ET Demands model is described as using basal crop coefficient ($K_{cb}$) curves, which are developed as a function of GDD. For this study, the $K_{cb}$ curves for annual crops are developed using baseline (historical) temperatures, while perennial $K_{cb}$ curves are developed using future projected temperatures.

Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest, are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, static phenology $K_{cb}$ curves were simulated for future periods where historical baseline temperatures were used for simulating planting, crop development, and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal $K_{cb}$ curve shapes for each annual crop, and only exhibit differences in daily $ET_c$ magnitudes due to daily $ET_o$ and precipitation differences. A detailed discussion on this static phenology approach is included in Reclamation (2015).

The future irrigation demands results cover mean annual precipitation, temperature, reference evapotranspiration ($ET_o$), crop evapotranspiration ($ET_c$), and net irrigation water requirement (NIWR, both depth and volume). Mean monthly values of perennial crop $ET_c$ for future time periods and scenarios are also presented to highlight potential changes in seasonal $ET_c$.

The future $ET_o$, $ET_c$ and NIWR subbasin and basin total estimates were calculated using the same methods as the historical baseline values. Specifically, the NIWR and $ET_c$ rates for each crop within a given HUC8 subbasin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 subbasin,

and all crop values are summed to calculate weighted average HUC8 subbasin NIWR and $ET_c$ rates. $ET_o$, $ET_c$ and NIWR estimates for the entire basin were calculated using the ratios of subbasin to basin irrigated acres.

The results are summarized in a series of figures and tables (similar in format to the WWCRA [Reclamation, 2015]), with appended detailed results and additional figures. The figures below show projected changes in temperature, precipitation, $ET_o$, $ET_c$, and NIWR for the CMIP5-based climate scenarios and both future time periods (2030s and 2070s). CMIP3-based figures are shown in Appendix C. Projected changes are presented as the difference from historical baseline averages for temperature, and percent change from baseline averages for all other variables. Projected absolute values of $ET_o$, $ET_c$, and NIWR for the different scenarios and time periods are also included in Appendix C.

Figure 4-6 illustrates the spatial distribution of projected precipitation percent change for the different scenarios and time periods. Depending on the scenario, basin average precipitation percent changes range from -7.4 percent to +20.8 percent for the 2070 time period (considering CMIP5-based scenarios), with the central tendency scenario showing a general increase throughout the basin.

Figure 4-7 shows the spatial distribution of projected mean temperature change for the different climate scenarios and time periods. Increased temperatures are shown for all scenarios and periods. with slightly larger projected mean temperature changes in the northeast portion of the basin for all scenarios. Depending on the scenario, basin average temperature changes range from 1.6 to 8.4 degrees F for the 2070s time period (considering CMIP5-based scenarios).

Figure 4-8 shows the spatial distribution of projected $ET_o$ percent change for different climate scenarios and time periods, and Table 4-19 provides a comparison of projected changes in annual $ET_o$ for the central tendency climate scenario. Similar to temperature, the projected percent change in $ET_o$ is larger in the northeast portions of the basin.

Figure 4-9 illustrates the spatial distribution of projected $ET_c$ percent change for different climate scenarios and future periods, and Table 4-20 provides a comparison of projected changes in annual $ET_c$ for the central tendency climate scenario. Spatial differences in the distribution of projected percent change in $ET_c$ are largely due to differences in crop type and historical baseline $ET_c$. The northeast portion of the basin is projected to experience the largest percent change increase for all projected time periods, largely due to the fact that the difference between the projected and historical baseline $ET_c$ is fairly large relative to the baseline estimate of $ET_c$ (see Figure 4-4). The predominant crops in the Upper Klamath Basin include alfalfa, pasture grass, other hay, and winter wheat. In the Lower Klamath Basin, where alfalfa, other hay, and spring wheat are the dominant crops, projected increases in $ET_c$ are lower. The Lower Klamath HUC8 subbasin has a projected decrease in $ET_c$, despite projected climate warming in all

HUC8 subbasins. The increase may be due to projected changes in the harvesting of grass hay, which is projected to occur earlier in the year.

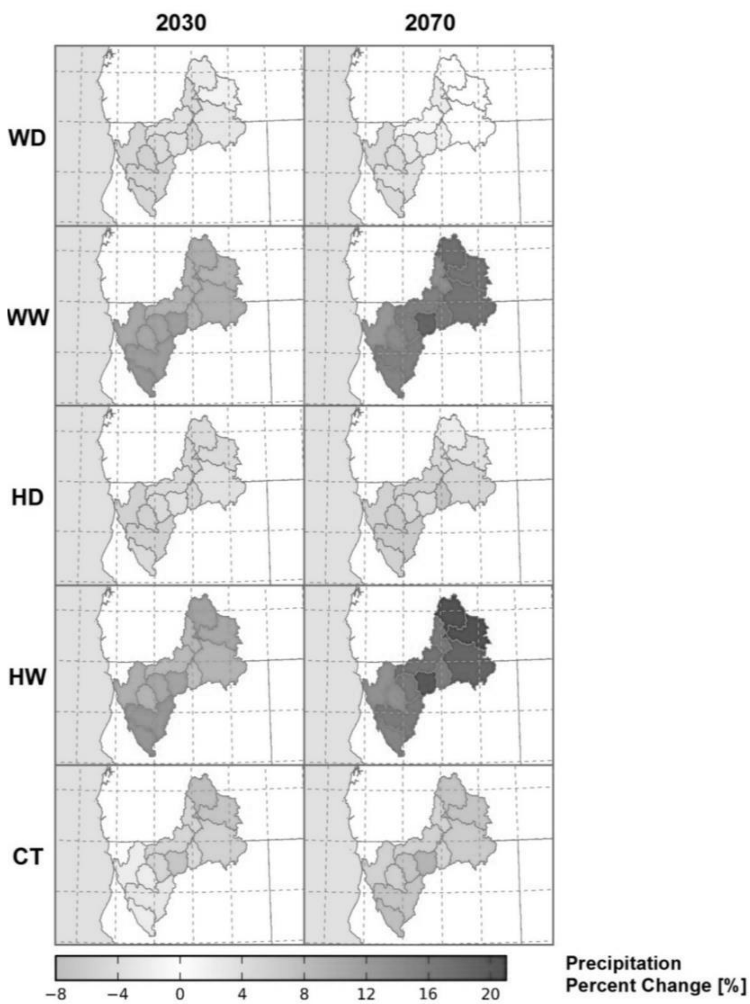


**Figure 4-6. Klamath River Basin - Spatial distribution of projected precipitation change for different climate scenarios and time periods (CMIP5 climate scenarios)**

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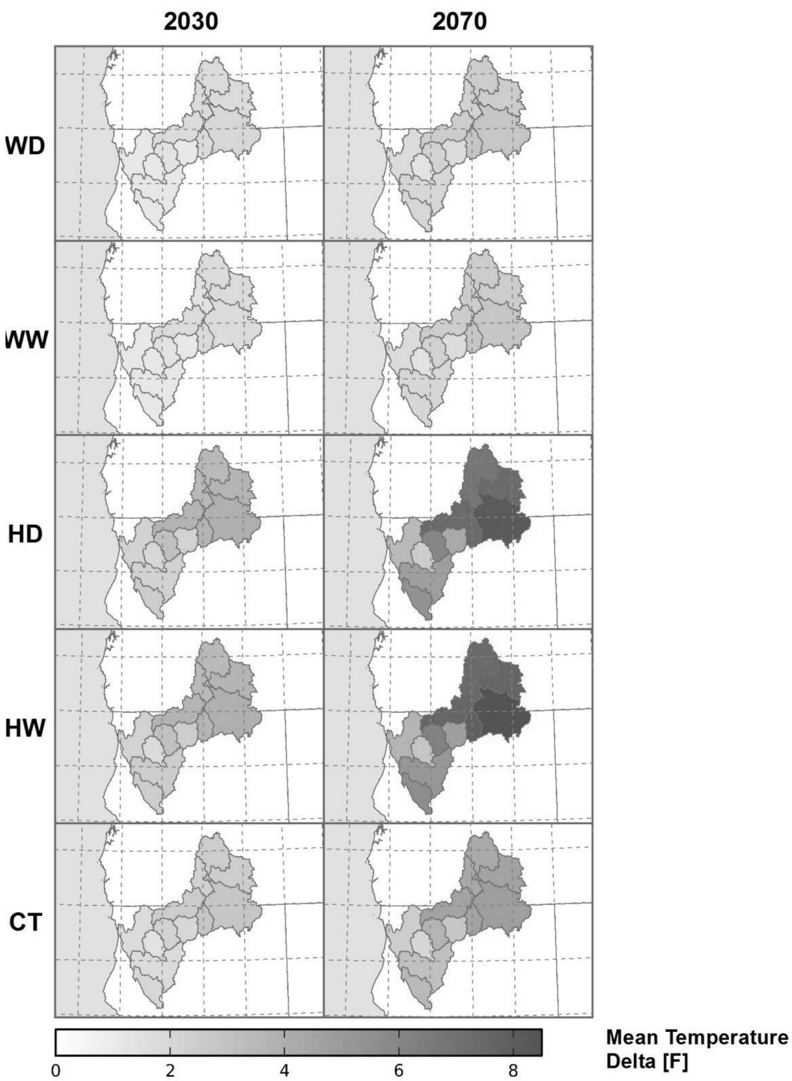


**Figure 4-7. Klamath River Basin - Spatial distribution of projected temperature change for different climate scenarios and time periods (CMIP5 climate scenarios)**

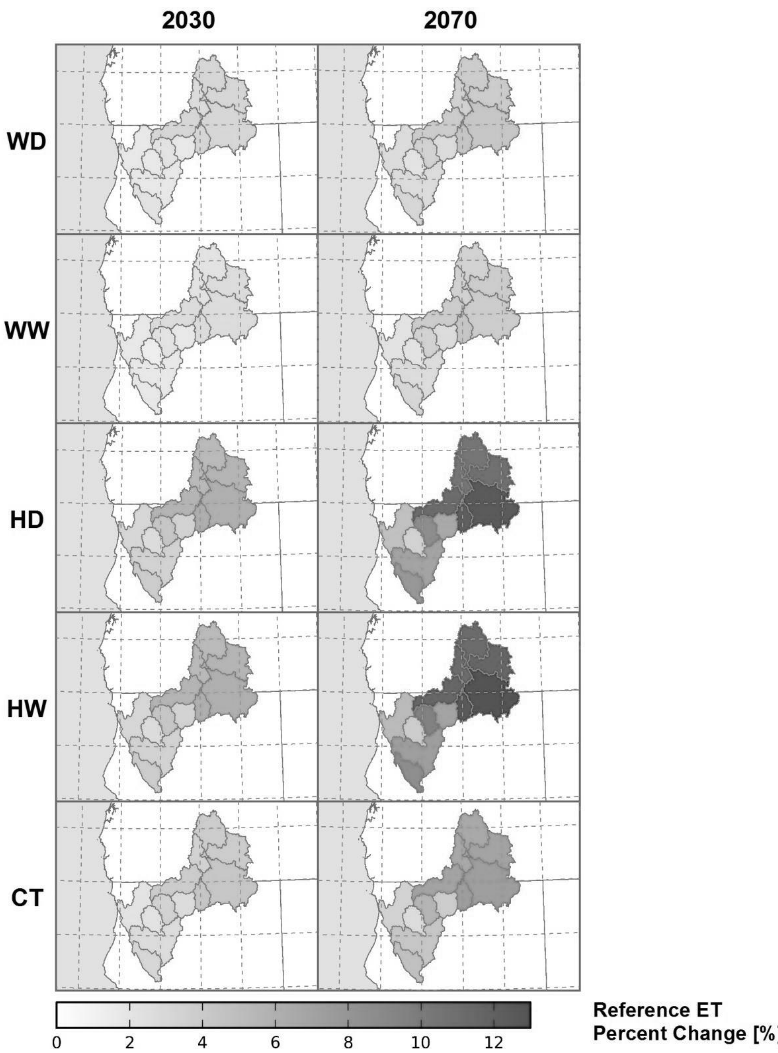


**Figure 4-8. Klamath River Basin - Spatial distribution of projected reference evapotranspiration percent change for different climate scenarios and time periods (CMIP5 climate scenarios)**

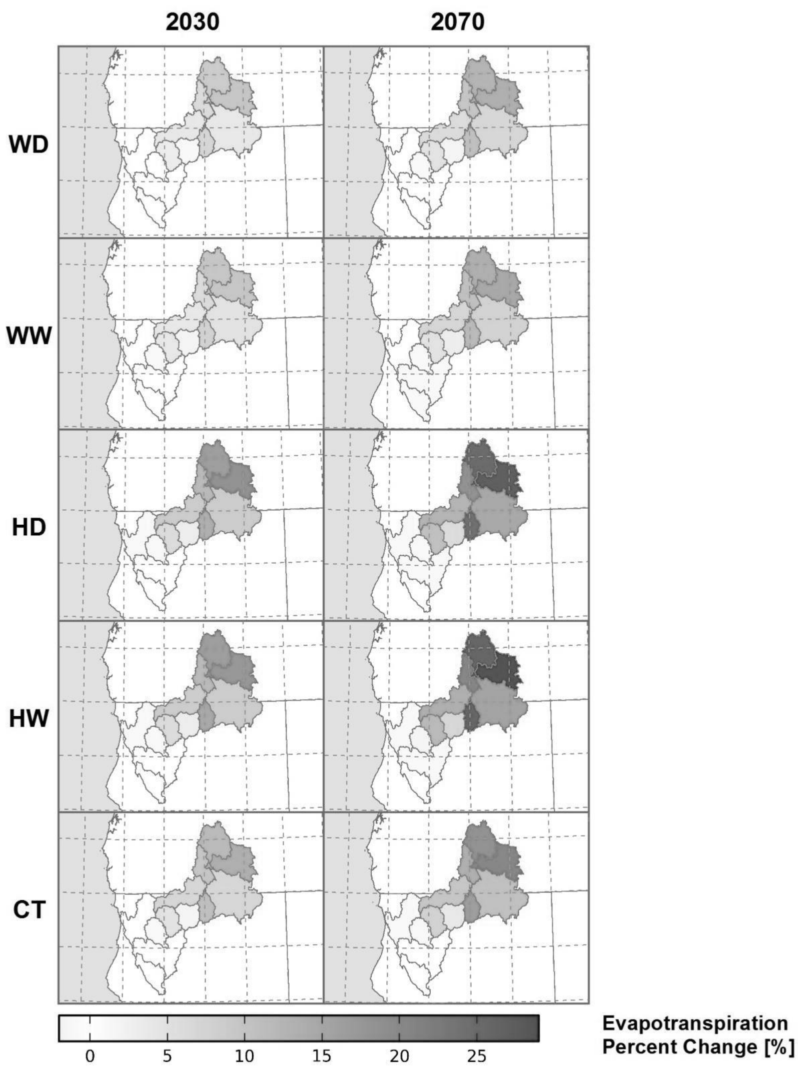


**Figure 4-9. Klamath River Basin - Spatial distribution of projected crop evapotranspiration percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios).**

**Table 4-19. Comparison of projected changes in annual reference evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 3.3% | 3.8% | 5.9% | 6.43% |
| HUC_18010202 | Sprague | 3.4% | 4.0% | 6.1% | 6.7% |
| HUC_18010203 | Upper Klamath Lake | 3.2% | 3.7% | 5.7% | 6.3% |
| HUC_18010204 | Lost | 3.6% | 4.3% | 6.7% | 7.4% |
| HUC_18010205 | Butte | 3.7% | 4.4% | 6.6% | 7.4% |
| HUC_18010206 | Upper Klamath | 3.5% | 4.1% | 6.1% | 6.8% |
| HUC_18010207 | Shasta | 2.3% | 2.7% | 3.7% | 4.2% |
| HUC_18010208 | Scott | 2.8% | 3.4% | 4.9% | 5.5% |
| HUC_18010209 | Lower Klamath | 2.1% | 2.4% | 3.2% | 3.4% |
| HUC_18010210 | Salmon | 2.0% | 2.3% | 2.8% | 2.9% |
| HUC_18010211 | Trinity | 2.3% | 2.7% | 3.9% | 4.3% |
| HUC_18010212 | South Fork Trinity | 2.5% | 3.0% | 4.4% | 4.8% |
| Total Basin | | 3.4% | 3.9% | 6.0% | 6.7% |

**Table 4-20. Comparison of projected changes in annual crop evapotranspiration for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins.**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 10.0% | 11.9% | 16.6% | 18.3% |
| HUC_18010202 | Sprague | 11.6% | 13.8% | 18.54% | 20.4% |
| HUC_18010203 | Upper Klamath Lake | 6.9% | 9.9% | 12.8% | 14.0% |
| HUC_18010204 | Lost | 5.7% | 6.8% | 9.6% | 10.7% |
| HUC_18010205 | Butte | 9.1% | 10.8% | 14.8% | 16.1% |
| HUC_18010206 | Upper Klamath | 5.4% | 6.6% | 8.9% | 9.7% |
| HUC_18010207 | Shasta | 2.2% | 2.6% | 3.9% | 4.4% |
| HUC_18010208 | Scott | 4.2% | 4.9% | 6.6% | 7.6% |
| HUC_18010209 | Lower Klamath | -0.7% | -0.9% | -1.1% | -1.2% |
| HUC_18010210 | Salmon | 1.0% | 1.1% | 1.3% | 1.4% |
| HUC_18010211 | Trinity | 0.7% | 0.8% | 0.8% | 0.9% |
| HUC_18010212 | South Fork Trinity | 0.8% | 0.9% | 0.7% | 0.6% |
| Total Basin | | 6.1% | 7.5% | 10.3% | 11.4% |

All HUC8 subbasins show positive $ET_c$ increases or no change, with the exception of the western-most HUC8 subbasin which exhibits slight decreases in $ET_c$ under all scenarios by 2070 due to earlier harvest of grass hay.

The spatial distribution of projected NIWR percent change for different climate scenarios and time periods is shown in Figure 4-10, and a comparison of projected changes in annual NIWR for the central tendency climate scenario is provided in

Table 4-21. The NIWR incorporates growing season and non-growing season soil moisture gains and losses from precipitation, bare soil evaporation, and ET; therefore spatial variations in the distribution of NIWR percent change for different time periods and scenarios are a function of respective $ET_c$ (Figure 4-9) and precipitation (Figure 4-6) distributions. For example, under the HD scenario precipitation is projected to decrease, whereas under the HW scenario precipitation is projected to increase. This results in NIWR increasing less in the HW scenario than in the HD scenario, though in both scenarios ETc changes are nearly identical.

**Table 4-21. Comparison of projected changes in annual NIWR for the central tendency climate scenario, compared with the historical baseline (1950–1999) for the Klamath River Basin and HUC8 sub-basins**

| HUC | Name | CMIP3 2030 | CMIP5 2030 | CMIP3 2070 | CMIP5 2070 |
|---|---|---|---|---|---|
| HUC_18010201 | Williamson | 16.1% | 19.0% | 26.1% | 26.1% |
| HUC_18010202 | Sprague | 16.7% | 18.4% | 24.1% | 25.0% |
| HUC_18010203 | Upper Klamath Lake | 10.5% | 12.0% | 17.2% | 17.5% |
| HUC_18010204 | Lost | 8. 6% | 9.4% | 13.8% | 14.2% |
| HUC_18010205 | Butte | 12.7% | 13.9% | 20.5% | 20.4% |
| HUC_18010206 | Upper Klamath | 5.7% | 5.7% | 10.7% | 10.4% |
| HUC_18010207 | Shasta | 3.5% | 2.8% | 4.8% | 4.4% |
| HUC_18010208 | Scott | 5.5% | 6.5% | 8.7% | 9.1% |
| HUC_18010209 | Lower Klamath | -1.0% | -1.8% | -1.4% | -2.8% |
| HUC_18010210 | Salmon | 1.3% | 1.4% | 2.4% | 1.8% |
| HUC_18010211 | Trinity | 0.8% | 0.8% | 1.1% | 0.9% |
| HUC_18010212 | South Fork Trinity | 1.0% | 0.1% | 0.9% | -0.3% |
| Total Basin | | 9.0% | 9.8% | 14.1% | 14.4% |

17-01174_012539;17-01174_012539;17-01174_012540;17-01174_012541;17-01174_012542;17-01174_012543;1...



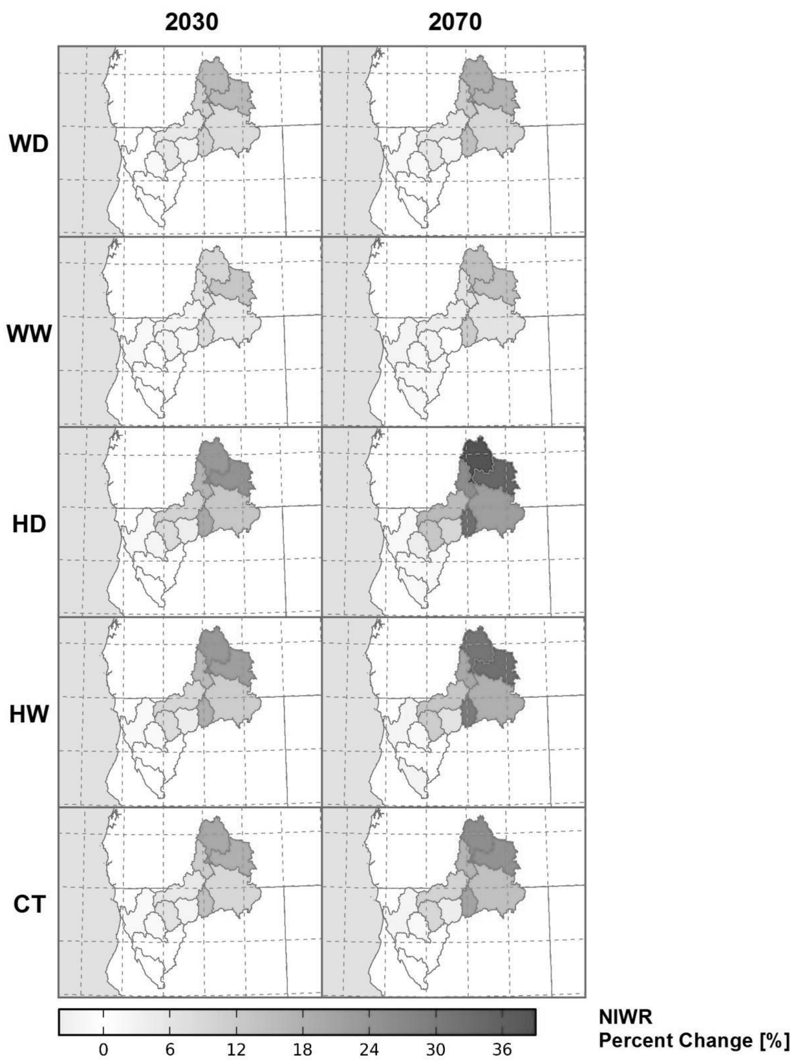


**Figure 4-10. Klamath River Basin - Spatial distribution of projected net irrigation water requirements percent change for different climate scenarios and time periods assuming static phenology for annual crops (CMIP5 climate scenarios)**

## Future Irrigation Demand Results

Assuming no change from current cropping patterns, the projected change in the central tendency scenario for the 2070s over the basin is 6-7% for reference ET (corresponding primarily to projected changes in temperature), while the projected change in crop ET is 10-11% (which incorporates changes in timing of crop growth and harvesting), and the projected change in NIWR is about 14% (which reflects changes in soil moisture throughout the year).

Figures 4-11, 4-12, and 4-13 illustrate the historical baseline and projected temporal distribution of mean daily $ET_c$ for three perennial crops (alfalfa, pasture grass, and grass hay, respectively) under each CMIP5-based climate change scenario for the 2030s and 2070s. The values plotted in these figures are based on model results for Met Node OR4511 (NWS/COOP Klamath Falls Ag. Station).

Figure 4-11 shows slight but noticeable shifts in the growing season length and alfalfa cutting cycles relative to historical baseline conditions by the 2030s (left). By the 2070s time period (Figure 4-11, right) significant shifts in growing season length, crop development, and cutting cycles are noticeable relative to baseline conditions, with the HW and HD scenarios exhibiting the most extreme changes. These simulations assume established crops rather than first year plantings. Projected changes in $ET_c$ are primarily realized through earlier green-up of alfalfa hay and changes in its cutting pattern. Senescence of the crop is delayed somewhat, but is primarily driven by day length. Maximum mean daily $ET_c$ during the warmest part of the year is not projected to increase substantially, primarily because plants have a maximum rate at which they can evapotranspire despite further increases in temperature.

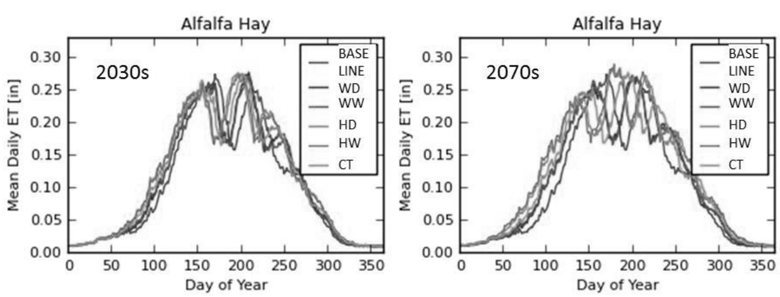


**Figure 4-11. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily alfalfa evapotranspiration for all CMIP5-based scenarios and time periods**

Figure 4-12 shows simulated mean daily $ET_c$ of pasture grass; similar changes in green-up and increases in growing season length and $ET_c$ are projected when compared to alfalfa, with the HW and HD scenarios having the most extreme seasonal changes.

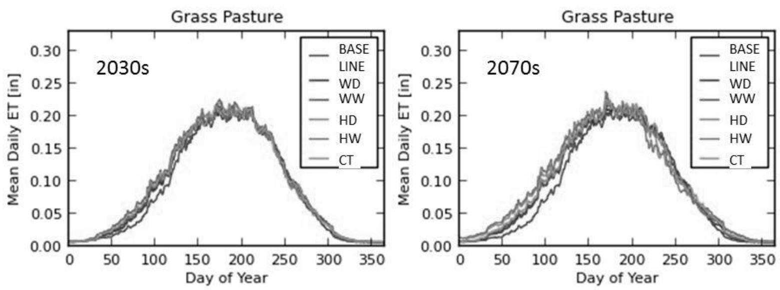


**Figure 4-12. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily pasture grass evapotranspiration for all CMIP5-based scenarios and time periods**

Figure 4-13 shows simulated mean daily $ET_c$ of grass hay. As with alfalfa and pasture grass, earlier green-up and increased mean daily $ET_c$ are slight for the 2030s and more pronounced for the 2070s. However, for the 2070s HW and HD scenarios, the overall growth period shifts forward rather than increasing in length. This is apparently due to the crop maturing earlier because of increased $ET_c$ early in the growing season under higher temperatures.

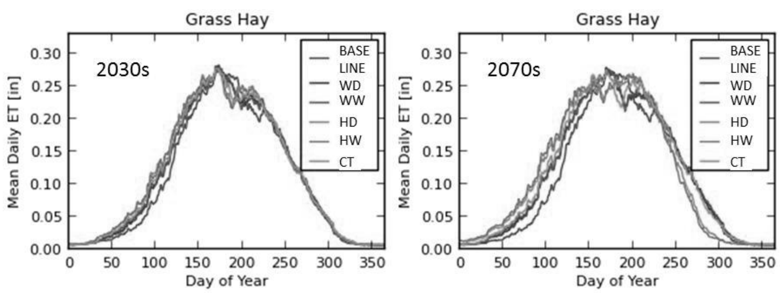


**Figure 4-13. Klamath River Basin – COOP Station OR4511 (NWS/COOP Klamath Falls Ag. Station) baseline and projected mean daily grass hay evapotranspiration for all CMIP5-based scenarios and time periods**

**Municipal and Industrial**

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed current per capita demands will change as a function of changes in landscape irrigation demands due to climate change. Socio-economic factors that could cause changes in per capita demand, such as water conservation, reduced landscape areas, etc., are not accounted for in this chapter but are evaluated as potential adaptation strategies in Chapter 6. As previously discussed, 40 percent of total M&I use is assumed to be consumed through landscape irrigation.

The first step in estimating future M&I demands is to calculate the future base demands based on current demands and future population growth estimates (i.e., including growth scenario but no climate change scenarios). The base future demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the five climate change scenarios (WW, WD, CT, HW, and HD) using the two GCM projection datasets (CMIP3 and CMIP5). Forty percent of the base future demand estimate for a given period and scenario is increased based on the ET Demands model results.

The future M&I demand estimates for Klamath, Siskiyou, and Trinity Counties were calculated based on the 2005 USGS Water Use Program estimates and population growth rates published by the California Department of Finance[29] and Oregon Office of Economic Analysis.[30] Since the California and Oregon projections are for 2010 through 2060 and 2050 in five-year increments, respectively, it is assumed the growth rates from 2005 to 2015 are uniform as well for 2050–2070 (Oregon) and 2060–2070 (California). The product of the 2030 and 2070 county population growth rates and the 2005 county M&I estimates yields the base M&I demands for each county.

For the municipalities with domestic water supply systems in Del Norte, Humboldt, and Modoc Counties (Hoopa, Klamath, Newell, Orleans, and Willow Creek, all in California), county population growth rates published by the California Department of Finance were applied to the current (2010) population estimates for calculating future population estimates. The product of the 2030 and 2070 population projections and the current per capita demand estimates yields the base M&I demands for each of the systems in these municipalities.

As discussed above, each of the M&I base consumptive use estimates are adjusted for climate change. Figure 4-14 provides a summary of projected changes in M&I consumptive use for each county and each climate change scenario. The 2030 M&I consumptive use totals for all counties range from 9,759 AFY to

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29 http://www.dof.ca.gov/research/demographic/reports/projections/P-1/
30 http://www.dof.ca.gov/research/demographic/reports/projections/P-1/

10,065 AFY and the 2070 estimate totals range from 11,003 AFY to 11,747 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

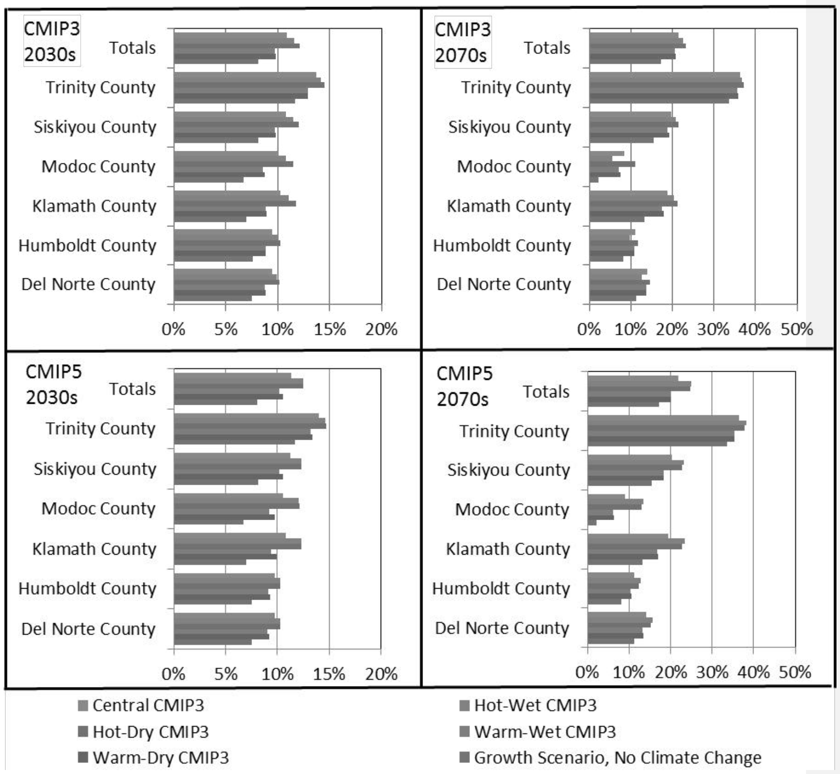


**Figure 4-14. Summary of future municipal and industrial consumptive use estimates (percent change)**

**Rural Domestic**

Future rural domestic water demand estimates were calculated based on population growth projections and climate change scenarios in the same manner as the M&I estimates discussed above. The same portion of total use for landscape irrigation is assumed (40 percent). Therefore, projections of future rural domestic use include only the consumptive portion of total use.

As discussed under Section 4.2, Current Demand, it is assumed the demands associated with the limited number of rural domestic water users in the portions of the basin in Del Norte and Humboldt Counties in California and Lake and

Jackson Counties in Oregon are negligible. Estimates were therefore calculated for Modoc, Siskiyou, and Trinity Counties in California and Klamath County in Oregon. The population projections used in the calculations are based on the 2005 USGS Water Use Program information and county population projections published by the California Department of Finance and Oregon Office of Economic Analysis.

Figure 4-15 provides a summary of projected change in rural domestic consumptive use for each county and each climate change scenario. The 2030s estimate totals for all counties range from 5,013 AFY to 5,190 AFY and the 2070s estimate totals range from 5,644 AFY to 6,030 AFY. Appendix C, Section 4.0 contains summary tables supporting these figures, including both projected values and projected percent change.

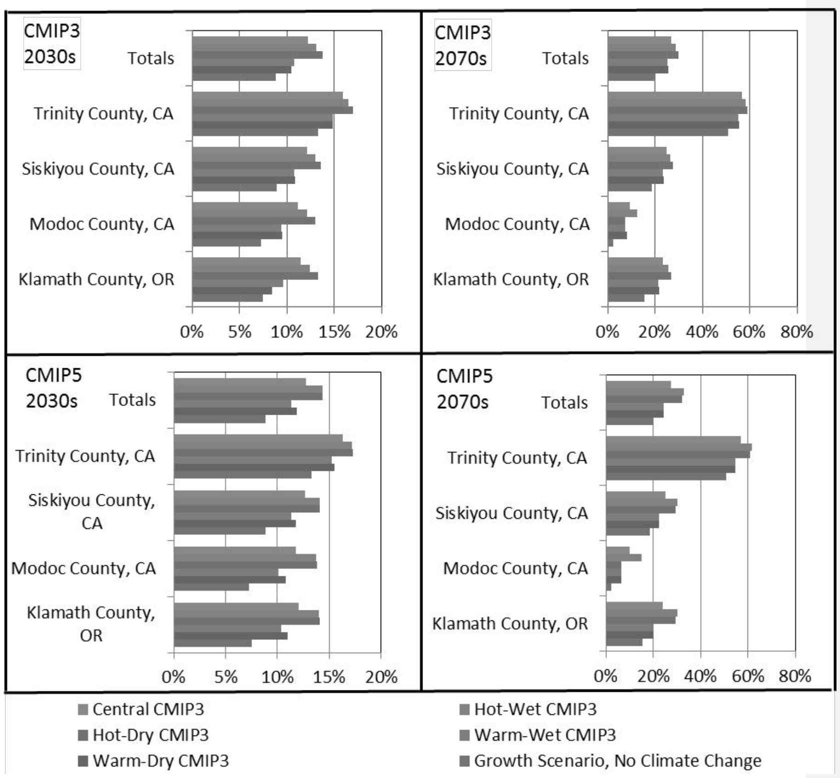


**Figure 4-15. Summary of future rural domestic consumptive water use estimates (percent change)**

#### *4.3.3.2 Wetlands*

Future wetland ET was computed based on projected mean daily alfalfa ET and pasture ET, using the same approach defined in Section 4.21, Human Influenced Consumptive Uses–Wetlands. Climate change scenarios using the HDe approach for each of the five quadrants of change for the 2030s and 2070s (using both CMIP3- and CMIP5-based projections) were also incorporated. The same relationships between wetland ET and alfalfa and pasture ET, according to the findings of Stannard et al. (2013), were used to determine projected mean annual wetland ET. Wetland ET is about 7 percent less than alfalfa ET during its average growing season and wetland ET is also about 18 percent greater than pasture ET during its average growing season. Mean annual wetland ET was computed using both relationships and averaged together for a single estimate.

Table 4-22 provides a summary of the resulting future wetland ET for each climate change scenario. The 2030s estimates range from 1,144,230 AFY to 1,228,916 AFY and the 2070s estimates range from 1,192,224 AFY to 1,319,673 AFY, compared with 1,089,061 AFY estimated for the mean annual historical wetland ET.

**Table 4-22. Summary of basin-wide projected changes in wetlands ET**

| Future Period and Scenario | Mean Annual Wetland ET (AFY) | Mean Annual Wetland ET (Percent Change) |
|---|---|---|
| Historical | 1,089,061 | - |
| 2030 Warm-Dry CMIP3 | 1,144,230 | 5% |
| 2030 Warm-Dry CMIP5 | 1,155,489 | 6% |
| 2030 Warm-Wet CMIP3 | 1,146,443 | 5% |
| 2030 Warm-Wet CMIP5 | 1,163,648 | 7% |
| 2030 Hot-Dry CMIP3 | 1,205,813 | 11% |
| 2030 Hot-Dry CMIP5 | 1,228,916 | 13% |
| 2030 Hot-Wet CMIP3 | 1,202,385 | 10% |
| 2030 Hot-Wet CMIP5 | 1,225,025 | 12% |
| 2030 Central CMIP3 | 1,175,143 | 8% |
| 2030 Central CMIP5 | 1,191,936 | 9% |
| 2070 Warm-Dry CMIP3 | 1,208,198 | 11% |
| 2070 Warm-Dry CMIP5 | 1,192,224 | 9% |
| 2070 Warm-Wet CMIP3 | 1,219,044 | 12% |
| 2070 Warm-Wet CMIP5 | 1,203,335 | 10% |
| 2070 Hot-Dry CMIP3 | 1,260,874 | 16% |
| 2070 Hot-Dry CMIP5 | 1,300,472 | 19% |
| 2070 Hot-Wet CMIP3 | 1,271,150 | 17% |
| 2070 Hot-Wet CMIP5 | 1,319,673 | 21% |
| 2070 Central CMIP3 | 1,237,064 | 14% |
| 2070 Central CMIP5 | 1,246,884 | 14% |

#### *4.3.3.3 Lake and Reservoir Evaporation*

The previously discussed CRLE model that was used to estimate historical baseline average evaporation rates was also used to estimate future average rates for the 2030s and 2070s periods. The same HDe climate change scenarios temperature and precipitation data described under the future agricultural irrigation demands discussion were input to the model. The model results include mean monthly evaporation and net evaporation (evaporation minus precipitation) rates for all of the reservoirs included in Table 4-14. The results for Upper Klamath Lake and Clair Engle Lake are discussed below, and the results for the other reservoirs are included in Appendix C, Section 5.0

Figures 4-16 and 4-17 show Upper Klamath Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and the historical baseline (1950–1999). The simulated impact of heat storage is negligible due to the shallow depth of Upper Klamath Lake. The magnitude of projected monthly evaporation and net evaporation increase is greatest during July, and least during fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Upper Klamath Lake is 5.5 and 5.4 percent (2.4 and 1.1 inches). Values for all scenarios are included in Appendix C, Section 5.0.

Figures 4-18 and 4-19 show Clair Engle Lake mean-monthly estimated evaporation and net evaporation, respectively, for the various climate change scenarios and historical baseline (1950–1999). The simulated impact of heat storage due to the depth of Clair Engle Lake can be seen in the lag in peak evaporation relative to peak air temperatures (August versus July). Also, the relatively high precipitation rates result in negative net evaporation under all scenarios and the historical baseline. The magnitude of projected monthly evaporation and net evaporation increase is greatest during August, and least during the fall and winter months. Under the central-tendency scenario and CMIP5 projection, the magnitude of annual evaporation and net evaporation increase from the baseline to the 2070s time period for Clair Engle Lake is 5.7 and 9.0 percent (2.3 and -2.3 inches), respectively. Values for all scenarios are included in Appendix C, Section 5.0.

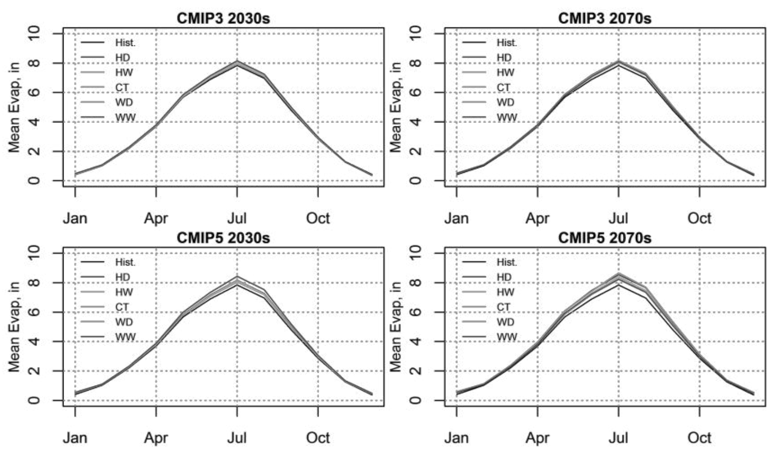


**Figure 4-16. Summary projected mean monthly evaporation at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

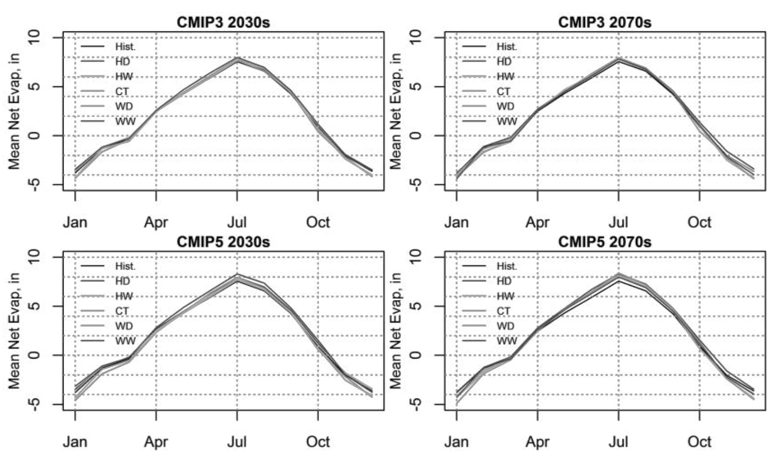


**Figure 4-17. Summary projected mean monthly net evaporation (evaporation – precipitation) at Upper Klamath Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

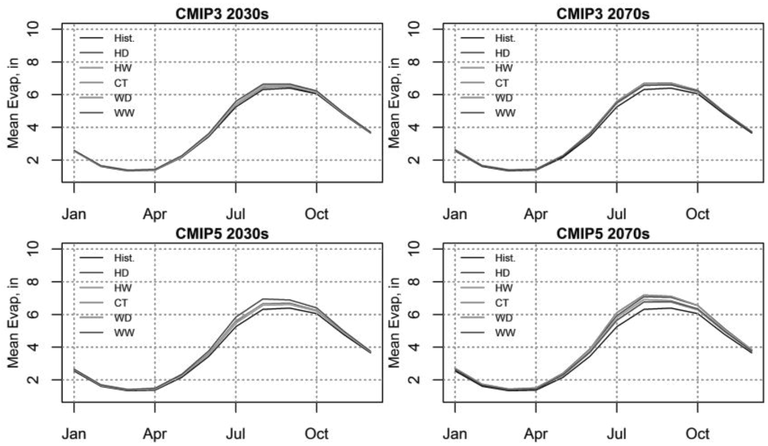


**Figure 4-18. Summary projected mean monthly evaporation at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

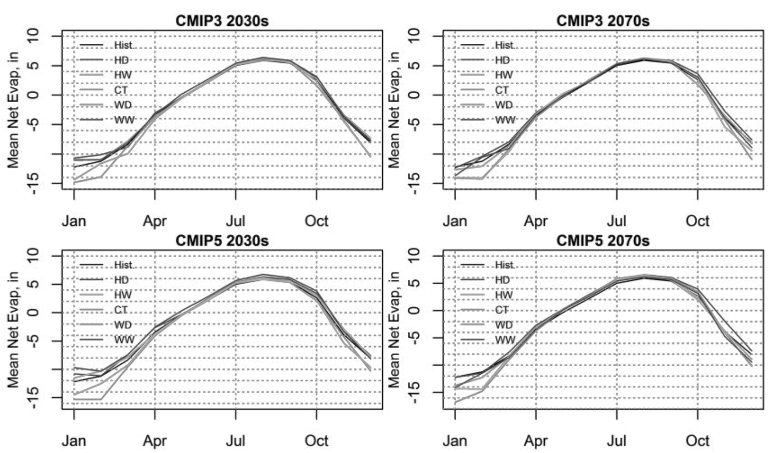


**Figure 4-19. Summary projected mean monthly net evaporation (evaporation – precipitation) at Clair Engle Lake for 5 climate change scenarios, including CMIP3 and CMIP5 projections for the 2030s and 2070s**

#### *4.3.3.4 Non-Consumptive Uses*

The effects of climate change on these uses (including recreation, environmental resources, hydropower, and aquaculture) are evaluated as part of the system reliability analysis in Chapter 5. In Chapter 5, the impacts are discussed in terms of factors such as exceedance of water quality criteria, flow or water level targets, and loss of power generation due to changing flows.

## 4.4 Uncertainties Associated with Impacts Assessment Approach

The Chapter 3 discussions on uncertainties associated with the various aspects of the Klamath River Basin Study water supply assessment covered many topics that also apply to the demands assessment. These topics include global climate forcing and simulation, climate projection bias correction and spatial downscaling, and climate projections from CMIP3 and CMIP5. Brief discussions of the limitations and uncertainties associated with quantification of water demands are presented below. A detailed discussion of uncertainties associated with the models used to estimate net irrigation water requirements (ET Demands) and reservoir evaporation (CRLE) are presented in Reclamation (2015) and are not detailed here.

**Commented [GIM5]:** I would add something here in light of the revised discussion in Section 3.9

### 4.4.1 Agricultural Irrigation

There are numerous uncertainties and limitations in modeling reference ET, crop ET, and net irrigation water requirements. One source of uncertainty is associated with underlying assumptions in modeling, such as static cropping patterns and farming practices. This study uses data provided by Reclamation's Klamath Basin Area Office for Klamath Project lands and the USDA crop land data layer for the remainder of the basin as the sources for quantifying the types of crops grown in the Klamath River Basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amount of irrigated area would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of net irrigation water requirements. Precipitation runoff and soil water holding capacity are a function of soil type, and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 subbasin for which a weighted average soil type was calculated, as described in Reclamation (2015).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future

periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands, were not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using the assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

### 4.4.2 Municipal and Industrial and Rural Domestic

Uncertainties associated with M&I and rural domestic demands are related to the assumed population projections and per capita demand rates used, and the assumed landscape irrigation portion of the overall demand (40 percent).

### 4.4.3 Wetlands

Evapotranspiration from wetlands is difficult to quantify and a limited number of studies have been conducted in this area of research. Wetlands are biologically diverse and quantification of ET requires expensive long-term monitoring. Existing studies often based their findings on data collected over a limited time period, generally a few years, contributing to the uncertainty around their estimates. The Klamath River Basin Study utilizes available studies to estimate mean annual wetland ET. Although there is relatively high uncertainty surrounding the estimates of wetland ET in this study, they generally corroborate other existing studies and provide a best estimate of mean annual wetland ET.

### 4.4.4 Reservoir Evaporation

Uncertainties in estimated reservoir evaporation are largely centered on CRLE energy balance considerations, specifically heat storage and advection of heat in air and water into and out of the reservoir. One important limitation of the CRLE model is its reliance on energy balance without consideration of the effects of windspeed on evaporation. However, one could argue that using an approach that heavily relies on windspeed, and is therefore extremely sensitive to uncertainties in windspeed (i.e., the aerodynamic-mass transfer or combination approach), may actually increase evaporation uncertainty, especially under future climates where projections of near surface local scale windspeed estimates are extremely uncertain.

It is significant that reservoir evaporation and net evaporation (evaporation minus precipitation) demands were estimated in terms of annual rates or depths rather

than volumes. These rates were estimated based on average historical conditions and a more rigorous analysis would be required to model evaporation under predicted future reservoir conditions. Future research in the Klamath River Basin could involve adjusting the CRLE model to accommodate projections of future reservoir conditions.

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# Chapter 5
# Klamath River Basin Study
# System Reliability Analysis

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# Chapter 5
# System Reliability Analysis

## 5.1 Introduction

The Klamath River Basin Study takes a comprehensive approach to evaluate water supply and demand over the entire watershed and develop adaptation strategies to work toward future water security. Reclamation developed the Basin Studies Program as a means of fulfilling obligations outlined in the SECUREWater Act of 2009 (P.L. 111-11) and Interior's Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. Basin studies are conducted by means of an equal 50 percent cost share between non-federal cost share partners and Reclamation to facilitate collaboration in identifying adaptation strategies for water management. Studies are typically completed within a three-year timeframe. The purpose of the Basin Study is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify and evaluate potential adaptation strategies which may reduce any identified imbalances.

This chapter discusses the methodology for evaluating gaps in water supply and demand and summarizes the reliability of the Klamath River system in achieving numerous defined measures, based on both historical data and projected future conditions.

Previous chapters of the Basin Study include an introduction and background for the study (Chapter 1), a discussion of various interrelated activities in the watershed (Chapter 2), an assessment of historical and future water supply in the watershed (Chapter 3), and an assessment of historical and future water demand in the watershed (Chapter 4). Chapter 6 discusses the development and evaluation of adaptation strategies for reducing gaps in water supply and demand within the system reliability framework discussed in this chapter. Figure 5-1 provides an overall schematic of the Basin Study approach to provide context for Chapter 5.

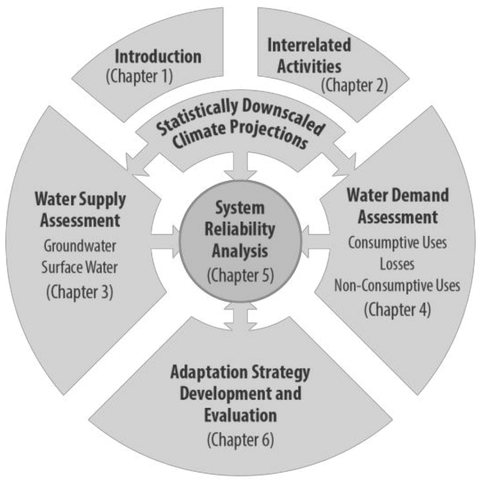



**Figure 5-1. Overall approach of Klamath River Basin Study, highlighting Chapter 5**

## 5.2 System Reliability Methodology

The Basin Study developed a framework for evaluating projected future water supply and demand conditions in a changing climate. This framework includes scenarios for characterizing projected future conditions, along with development and implementation of connected modeling components, with the end goal of evaluating system risk and reliability in the basin. Additionally, the Basin Study system risk and reliability analysis evaluates impacts of climate change on non-consumptive uses, which are those that do not result in a net decrease of the overall available water supply. In the Klamath River Basin non-consumptive uses include maintaining flows and water levels for recreation (boating, fishing, wildlife viewing, etc.) and water needs to support fish and wildlife and hydropower production, among others.

This section briefly reviews the scenarios developed and corresponding modeling components implemented to provide inputs to a water management model. More detailed discussions of historical and projected water supply and demand are provided in Chapters 3 and 4, respectively. This section then provides a detailed description of the tools developed to evaluate system reliability and potential vulnerabilities to climate change impacts. Results from the analysis are evaluated using basin-wide response variables and defined measures to quantify and summarize projected changes in system reliability due to climate change.

### 5.2.1 Characterizing Historical and Future Conditions

The assessment of impacts of climate change on Klamath River Basin water supply is focused on two future time horizons: the 2030s (represented by the mean from 2020–2049) and the 2070s (represented by the mean from 2060–2089). Future projections are compared with a historical reference period of 1950–1999 to evaluate the effects of climate change on water supply.

Historical trends in total annual precipitation and mean annual temperature over water years 1950–1999 were computed based on the spatially distributed (i.e., gridded) historical climate dataset developed by Maurer et al. (2002). This climate dataset has been widely used as the basis for a range of hydrologic modeling studies, including studies of climate change impacts. The same dataset was used for analysis of historical conditions in the Basin Study. Historical trends in April 1 SWE, total annual runoff, total annual ET, and June 1 soil moisture were computed based on historical simulations from the VIC hydrologic model (described in detail in Chapter 3).

Historical trends in annual precipitation over the Klamath River Basin indicate a small increasing trend over the basin as a whole (about 0.8 inches, or +2 percent, over the 50 year period). All portions of the Klamath River Basin exhibit increasing trends in historical mean annual average temperature over 1950–1999. Due in part to historical warming trends, the Klamath River Basin exhibits decreases in April 1 SWE basin-wide. Mean annual runoff over the period 1950–1999 has decreased basin-wide by about 7 percent. ET, as computed by the VIC hydrology model, has exhibited an increase of about 8 percent basin-wide. Soil moisture on June 1 (historically the month of maximum soil moisture) has increased slightly over the basin as a whole. The only statistically significant trend at the 95th percentile level computed with the historical data is mean annual temperature.

The development of climate change scenarios is described in Chapter 3, Section 3.5.1.1 Climate Projections. The scenarios are generated by computing change factors between chosen future time horizons (in this case the 2030s and 2070s) and a chosen historical period (in this case 1950–1999). The Basin Study, consistent with other existing and ongoing basin studies throughout the western United States, utilizes available climate projections to derive a smaller number of climate change scenarios to inform long term planning. Review of climate projections over the Klamath River Basin suggests a warmer future (no projections suggest cooling may occur) with a range of drier to wetter conditions, compared to history. As such, we chose ensembles of climate projections that bracket the range of potential futures, from less to more warming and drier to wetter conditions, for a total of five ensembles of climate scenarios for each of two sets of projections (CMIP3 and CMIP5). These are warm-wet (WW), warm-dry (WD), hot-wet (HW), hot-dry (HD), and central tendency (CT). These scenarios were derived using an ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2011d).

Projections of future water supply and demand using the above-discussed climate change scenarios and evaluated in Chapters 3 and 4, respectively, are briefly summarized below. Following this brief summary is a discussion of the methodology used to evaluate projected changes in managed streamflow and water temperature at various locations throughout the basin.

#### *5.2.1.1 Water Supply*

- By the 2050s, annual temperature will be largely outside the range of historical variability; precipitation will be largely within the recent instrumental record.
- Precipitation projections generally indicate wetter winters and slightly drier summers, with increased temperatures in all seasons.
- A decrease in April 1 SWE is projected on the order of 34 to 40 percent for the 2030s and close to 60 percent for the 2070s, and projected increases in annual runoff are 7 to 12 percent for the 2030s and 14 to 15 percent for the 2070s. Projected increases in mean annual runoff are offset by projected changes in April 1 SWE, primarily due to projected increases in mean annual precipitation,
- For sub-basins that are influenced in part by snowmelt, seasonal streamflow peaks are projected to shift toward earlier in the year and overall volumes may increase. For sub-basins that are primarily rainfall-driven, the timing of seasonal peak runoff is not projected to shift substantially; however, the central tendency scenario indicates an overall increase in streamflow volume.
- An increase in groundwater head is projected in mountainous recharge areas of the Upper Klamath Basin (less than 9 percent), as is a change in groundwater discharge to streams, while little change is expected in populated interior parts of the basin.

#### *5.2.1.2 Water Demands (Human Influenced)*

- Agricultural irrigation demand (surface and groundwater) is the largest human influenced consumptive use in the basin.
- Projected changes in total consumptive uses are 12 or 13 percent (CMIP3 and CMIP5 scenarios, respectively) for the 2030s and 17 or 18 percent for the 2070s. Consumptive uses include agricultural irrigation, net reservoir evaporation, municipal and industrial (M&I) and rural domestic demands, and wetlands.
- The effects of climate change on other non-consumptive uses including recreation, environmental resources, hydropower, and aquaculture are evaluated as part of this chapter.

### 5.2.2 Basin-Wide Responses

The evaluation of climate change impacts on system risk and reliability has two primary components: basin-wide system response at various basin locations, and specific performance measures that have been identified through discussions with regional resource managers, stakeholders, and others. Evaluation of basin-wide system response provides a general understanding of projected changes in managed conditions as a result of climate change and implemented adaptation strategies. Evaluation of system response to quantified measures provides a deeper understanding of climate change impacts on specific resources relevant to water management in the basin.

Basin-wide response variables include mean monthly conditions for the following locations:

- Mean monthly Upper Klamath Lake storage
- Mean monthly inflow to Klamath River at Keno
- Mean monthly streamflow, Klamath River at Iron Gate
- Mean monthly streamflow, Klamath River at Orleans, California
- Mean monthly streamflow, Klamath River near Klamath, California
- Mean monthly water temperature in the Klamath River near Klamath, California

This report includes analysis of historical and projected future changes in these basin-wide response variables, according to the developed Basin Study modeling framework. Subsequently, in Chapter 6, basin-wide response variables are evaluated for each of the adaptation strategies selected for exploring ways to reduce any identified water supply and demand gaps. Performance measures are described in more detail below.

### 5.2.3 Performance Measures

Performance measures are used to evaluate historical and future vulnerabilities to meeting water needs in the basin, and to facilitate the comparison of adaptation strategies to reduce any identified imbalances in water supply and demand.

Performance measures have been identified in accordance with the Basin Study Framework guidance document (Reclamation, 2009c) and span numerous resource categories, which include:

- Water deliveries – the ability for water to be delivered to water users
- Hydroelectric power resources
- Recreational resources – including Reclamation facilities and parts of the watershed impacted by Reclamation operations

- Ecological resources – including fish and wildlife habitat; applicable species listed as an endangered, threatened, or candidate species under the Endangered Species Act of 1973; species and habitat of cultural importance; and flow and water dependent ecological resiliency
- Water quality resources
- Flood control

Measures for each category were arrived at based on input from stakeholders and resource managers in the basin. Table 5-1 summarizes the performance measures. The following paragraphs describe each measure in more detail.

**Table 5-1. General description of performance measures**

| Resource Category | Measure Description | Location(s) | Measure Details |
|---|---|---|---|
| Water supplies | Total Klamath Project supply | Klamath Project | Calculated under 2013 Biological Opinion operating criteria. Compare result with full season Klamath Project supply of 390,000 acre-feet. |
| | Total Upper Klamath Lake seasonal supply | Upper Klamath Lake | End of February storage plus actual March through September inflow at Upper Klamath Lake |
| | Mean annual tributary flow | Shasta River; Scott River | Mean annual flow at USGS gages (USGS 11517500 Shasta River near Yreka; USGS 11519500 Scott River near Fort Jones) |
| Hydroelectric power resources | Hydropower production | Sum of J.C. Boyle power, COPCO 1 power, COPCO 2 power, Iron Gate power | Mean annual hydropower production summed over these facilities[31] |
| | Volume of spill | J.C. Boyle, COPCO 1, Iron Gate | Mean annual spill volume based on water year[1] |
| | Frequency of spill | J.C. Boyle, COPCO 1, Iron Gate | Mean number of spill days per water year at these facilities[1] |
| Recreational resources | Mean fishing days per year | Various mainstem Klamath River reaches | Mean number of days per year that flows are within acceptable ranges for select river reaches |

[31] Source: PacifiCorp

**Table 5-1. General description of performance measures**

| Resource Category | Measure Description | Location(s) | Measure Details |
|---|---|---|---|
| | Mean boating days per year | Various mainstem Klamath River reaches | Mean number of days per year that flows are within acceptable ranges for select river reaches |
| Ecological resources | Salmonid success | Shasta River; Scott River | Flow thresholds throughout the year[32] |
| | Delivery to refuge | Lower Klamath National Wildlife Refuge | Mean annual water delivery to refuge[33] |
| | Pool elevation | Clear Lake; Gerber Reservoir | Minimum elevation thresholds[34] |
| Water quality | Water temperature | Klamath River | Maximum weekly average temperature (MWAT) |
| Flood control | Frequency of flood control release | Upper Klamath Lake | Mean number of days per year that flood control releases are made from Upper Klamath Lake[35] |
| | Mean annual flood control release volume | Upper Klamath Lake | Mean annual volume of flood control releases from Upper Klamath Lake[5] |
| | Date of seasonal peak flow | J.C. Boyle, COPCO 1, Iron Gate | Mean date of the center of mass of the annual flow volume (by water year) at select locations[1] |

#### *5.2.3.1 Water Supplies – Klamath Project Water Supply*

There are two measures associated with Klamath Project water supply. The first measure is computed as the mean annual water supply to the Klamath Project, expressed as a percentage. The value may be compared with a full supply quantified as 390,000 acre-feet.

The second measure is computed as the sum of the end of February Upper Klamath Lake storage and the actual March through September Upper Klamath Lake inflow, averaged across the simulation years and expressed in units of a thousand acre-feet. The measure represents the total seasonal availability of water supply to be distributed among project responsibilities.

#### *5.2.3.2 Water Supplies – Mean Annual Tributary Flow in Shasta and Scott Rivers*

This measure is computed for two locations: USGS gages Shasta River near Yreka (11517500) and Scott River near Fort Jones (11519500). The measure is computed as the mean annual streamflow at these two locations. Effectively, the simulated streamflows represent the balance of supply and demand in these two

[32] Source: McBain and Trush (2014)
[33] Source: Klamath Basin National Wildlife Refuge Complex
[34] Source: Klamath Basin Area Office
[35] Source: Reclamation (2012d)

tributary watersheds to the Klamath River. Units are in cubic feet per second (cfs).

##### *5.2.3.3 Hydroelectric Power Resources – Hydropower Production*

This measure is computed as the sum of mean annual hydropower production at J.C. Boyle reservoir, COPCO 1 reservoir, COPCO 2 reservoir, and Iron Gate reservoir. Units of hydropower production are megawatts.

##### *5.2.3.4 Hydroelectric Power Resources – Spill Volume*

This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean spill per year in cfs.

##### *5.2.3.5 Hydroelectric Power Resources – Spill Frequency*

This measure is computed at three locations: J.C. Boyle reservoir, COPCO 1 reservoir, and Iron Gate reservoir. The measure is computed as the mean number of days per year that each of the reservoirs have spill.

##### *5.2.3.6 Recreational Resources – Mean Annual Fishing Days*

This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow (by the surface water management model) is within the target ranges for fishing in each river reach. Table 5-2 lists the recommended flow ranges for fishing.

**Table 5-2. Recommended target flow ranges for fishing within select reaches of the Klamath River**

| River Reach | Flow Target Ranges (cfs) |
|---|---|
| Keno Reach | 200-1,500 |
| J.C. Boyle | 200-1,000 |
| Hell's Corner Reach | 200-1,500 |
| COPCO 2 Bypass Reach | 50-600 |
| Iron Gate to Scott River | 800-4,000 |
| Scott River to Salmon River | 800-4,000 |
| Salmon River to Trinity River | 800-10,000 |
| Trinity River to ocean | 1,000-18,000 |

*Source: Interior and CDFG, 2012*

##### *5.2.3.7 Recreational Resources – Mean Annual Boating Days*

This measure is computed at eight locations along the mainstem Klamath River. The measure is computed as the mean number of days per year that simulated streamflow by the surface water management model is within the target ranges for river boating in each river reach. Table 5-3 lists the recommended flow ranges for river boating.

**Table 5-3. Recommended target flow ranges for boating within select reaches of the Klamath River**

| River Reach | Flow Target Ranges (cfs) |
|---|---|
| Keno Reach | 1,000-4,000 |
| J.C. Boyle | 1,300-1,800 |
| Hell's Corner Reach | 1,000-3,500 |
| COPCO 2 Bypass Reach | 600-1,500 |
| Iron Gate to Scott River | 800-4,000 |
| Scott River to Salmon River | 800-7,000 |
| Salmon River to Trinity River | 800-10,000 |
| Trinity River to ocean | 1,000-18,000 |

*Source: Interior and CDFG, 2012*

#### *5.2.3.8 Ecological Resources – Salmonid Success in Shasta and Scott Rivers*

This measure is computed at two locations: USGS gages Scott River near Fort Jones (11519500) and Shasta River near Yreka (11517500). The measure compares simulated daily flow to quantified dry year flow targets recommended by McBain and Trush (2014) for the Shasta River. A dry year has an exceedance probability of between 61 and 100 percent. The measure is computed as the total number of days in a model simulation that dry year flow targets are met or exceeded, divided by the total number of days in the simulation and presented as a percentage. Dry year flow targets recommended by McBain and Trush (2014) are summarized below in Table 5-4. Note that the flow targets were developed for the Shasta River, where mean annual flow (188 cfs) is less than one third that of the Scott River (669 cfs). However, for purposes of this analysis the same threshold flows were applied for the Scott River to explore the frequency of meeting those same target flows in the Scott River.

**Table 5-4. Dry Year (61–100 percent exceedance) flow targets for salmonids**

| Time Period | Dry Year Target (cfs) |
|---|---|
| January 1 – March 31 | 135 |
| April 1 – May 15 | 170 |
| May 16 – June 15 | 150 |
| June 16 – September 15 | 70 |
| September 16 September 30 | 70-90 |
| October 1 – October 16 | 125 |
| October 17 – October 30 | 125-150 |
| October 31 – December 31 | 150 |

*Source: McBain and Trush 2014*

#### *5.2.3.9 Ecological Resources –Water Delivery to Lower Klamath National Wildlife Refuge*

This measure is computed as the mean annual water supply to Lower Klamath National Wildlife Refuge as simulated by the surface water management model. The measure is expressed in acre-feet.

#### *5.2.3.10 Ecological Resources – Pool Elevation at Clear Lake and Gerber Reservoirs*
This measure is computed at two locations: Clear Lake and Gerber Reservoirs. The measure compares simulated pool elevations at these locations with minimum pool elevations quantified for survival of Lost River and shortnose suckers. Minimum pool elevation for Clear Lake is 4,520.6 feet, while the minimum pool elevation for Gerber Reservoir is 4798.1 feet. The measure is computed as the mean percent of days that simulated pool elevations are at or above target pool elevations.

#### *5.2.3.11 Water Quality – Water Temperature*
This measure is computed as the maximum weekly average temperature (MWAT) in the mainstem Klamath River. The MWAT is the highest seven-day moving average of the daily mean river temperature. This measure is computed using the RBM10 stream temperature model developed by Perry et al. (2011). Details of the river temperature modeling approach and implementation are discussed in Section 5.3.2, System Reliability Model Development – Water Temperature Model. The MWAT is computed for each year and the mean of these temperatures across the simulation years is presented as the measure. Table 5-5 summarizes classifications of Poor to Very Good conditions for fish, along with associated temperature ranges, provided in the SONCC ESU coho salmon recovery plan (NMFS 2012).

**Table 5-5. Maximum weekly average temperature recommendations from the SONCC ESU salmon recovery plan**

| Maximum Weekly Average Temperature (MWAT) Classification | Temperature Range (degrees C) | Temperature Range (degrees F) |
|---|---|---|
| Poor | > 17.6 | > 63.68 |
| Fair | 16-17 | 60.8-62.6 |
| Good: | 15-16 | 59-60.8 |
| Very Good | < 15 | < 59 |

*Source: NMFS 2012, Appendix B*

#### *5.2.3.12 Flood Control – Flood Control Release Frequency*
This measure is computed as the mean annual percent of days where release from Upper Klamath Lake is specifically for flood control purposes. The unit of the measure is percent of days.

#### *5.2.3.13 Flood Control – Flood Control Release Volume*
This measure is computed as the mean annual volume of releases from Upper Klamath Lake specifically for flood control purposes. The unit of the measure is thousands of acre-feet (KAF).

#### *5.2.3.14 Flood Control – Date of Seasonal Peak Flow*
This measure is computed as the mean date of the center of mass of the annual flow volume (by water year) at select locations. The center of mass is defined as

the time at which half of the mean annual flow has passed the location of interest. The measure is presented as the mean date over the simulation period.

## 5.3 System Reliability Model Development

This analysis utilizes developed historical and future water supply and demand as input to a system risk and reliability model framework. The modeling framework involves two main components: the implementation of a surface water management model to generate simulated managed streamflow throughout the basin, and the implementation of a river temperature model to generate simulated water temperature in the mainstem Klamath River. The modeling components are described below in more detail.

### 5.3.1 Surface Water Management Model

A RiverWare surface water management model (Zagona et al., 2001) was developed for use by the Klamath River Basin Study. The RiverWare software platform allows for evaluation of river flows based on rule-based operations, using logic statements and assigned rule priorities. The RiverWare platform has been used in many other studies conducted by Reclamation and others (e.g., Colorado River Basin Water Supply and Demand Study [Reclamation, 2012e]; St. Mary River and Milk River Basins Study [Reclamation, 2012f]).

The Klamath Basin RiverWare model is a daily timestep model based on two existing models for the Upper Klamath Basin and Lower Klamath Basin. The existing Upper Klamath Basin model, commonly referred to as the Klamath Basin Planning Model (KBPM), was developed to support the ESA consultations over the impacts of Klamath Project operations on the endangered SONCC ESU coho salmon (Reclamation, 2012d). The existing Lower Klamath Basin model was developed to support the environmental impacts assessment for removal of four of the mainstem Klamath River dams (Interior, Department of Commerce, NMFS, 2012).

The Klamath Basin RiverWare model encompasses the entire watershed including tributaries of Upper Klamath Lake, the Lost River system, and major Klamath River tributaries such as the Shasta River, Scott River, Indian Creek, Salmon River, and Trinity River. The model includes representation of eight reservoirs: Upper Klamath Lake, Clear Lake, Gerber Reservoir, Lake Ewauna, J.C. Boyle Reservoir, COPCO 1 Reservoir, COPCO 2 Reservoir, and Iron Gate Reservoir.

The Klamath Basin RiverWare model was developed over a historical time period of water years 1961 through 2013 to facilitate comparison of results with the KBPM model. The historical model incorporates historical water demand information, and simulated water supply information from the water supply assessment in Chapter 3 in order for model validation to be performed. Once simulated flows were reached that sufficiently compared with results from the KBPM model, a separate historical model was developed using a period of record

of water years 1969 through 1999. The latter model incorporates simulated historical information from the water supply and water demands assessments in Chapters 3 and 4, respectively. This model was used as the basis for comparison of simulated streamflows under the historical climate to those under climate change scenarios.

The level of detail of the Klamath Basin RiverWare model allows for evaluation of Klamath River flows and Klamath Project operations under the current 2013 non-jeopardy Biological Opinion for SONCC ESU coho salmon, as well as evaluation of climate change impacts on other parts of the basin, including the Lost River and major Klamath River tributaries listed above.

Inputs to the Klamath Basin RiverWare model include the following:

- simulated natural surface hydrology from the VIC hydrologic model at various locations within the basin
- simulated groundwater discharge to streams in the Upper Klamath Basin as produced by the Gannett et al. (2007) MODFLOW model
- agricultural irrigation water requirements by 8-digit hydrologic unit code (HUC) throughout the Klamath Basin as produced by the water demands assessment (Chapter 4)
- net reservoir evaporation rates as produced by the water demands assessment (Chapter 4)
- M&I and rural domestic demands as produced by the water demands assessment

Outputs from the Klamath Basin RiverWare model include the following:

- Simulated managed flow at various locations in the Klamath Basin
- Reservoir storage and elevations
- Deliveries to the Klamath Project, Lower Klamath National Wildlife Refuge (LKNWR), etc.
- Hydropower generation

### 5.3.2 Water Temperature Model

The Klamath River Basin Study incorporates analysis of historical and projected future Klamath River temperature using an existing river temperature model developed by Perry et al. (2011). The river temperature model, called River Basin Model-10 (RBM10), was developed for the Secretarial Determination on removal of four hydroelectric dams on the Klamath River. It simulates water temperatures in the mainstem Klamath River from the Link River to the mouth. In this

application, water temperatures are computed at the Klamath River near Klamath, California.

RBM10 uses a simple equilibrium flow model, assuming discharge in each river segment on each day is transmitted downstream instantaneously. The model uses a heat budget formulation to quantify heat flux at the air-water interface. Inputs for the heat budget were calculated from daily-mean meteorological data including net shortwave solar radiation, net longwave atmospheric radiation, air temperature, wind speed, vapor pressure, and a psychrometric constant needed to calculate the Bowen ratio.

For the Klamath River Basin Study application, meteorological inputs used as part of the water supply assessment described in Chapter 3 were adjusted to match the statistics of the meteorological data used by Perry et al. (2011) in their study of the impacts of climate change and dam removal on Klamath River water temperatures. Input streamflows were taken directly from the Klamath Basin RiverWare model at locations consistent with the Perry et al. (2011) study. It should be noted that input streamflows were increased by 10 cfs in some Upper Klamath Basin reaches to prevent negative streamflows in the mainstem Klamath River. Negative Klamath River flows were possible due to the difference in handling of streamflow routing by the RBM10 and Klamath River Basin RiverWare models.

## 5.4 System Reliability and Impacts Assessment

Historical and projected future reliability of the Klamath River Basin water supply is summarized in two ways: through basin-wide response variables, and through identified reliability measures that were defined for six resource categories. This methodology was previously described in Section 5.2, System Reliability Methodology.

This chapter summarizes historical and projected changes in system reliability due to climate change alone. Chapter 6 discusses how various basin-wide responses and select measures may change as a result of implementing adaptation strategies.

### Impacts on Reservoir Storage

Mean end of month storage in Upper Klamath Lake generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, end of month reservoir storage did not historically fluctuate substantially through the year. Projections for the 2030s and 2070s indicate peak storage is likely to remain about the same or increase slightly.

17-01174_012539;17-01174_012539;17-01174_012540;17-01174_012541;17-01174_012542;17-01174_012543;1...



### 5.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of historical and projected future basin-wide responses to water supply and demand allows for a general understanding of how the basin may respond as a result of climate change. Historical and projected future changes in water availability of the managed Klamath River system are provided below. Data supporting the following figures are provided in Appendix D.

#### *5.4.1.1 Upper Klamath Lake Storage*

Mean monthly end of month (EOM) storage in Upper Klamath Lake is summarized in Figure 5-2. Maximum storage historically occurs at the end of May, while minimum storage occurs in November. Under the climate change scenarios, mean EOM storage generally experiences earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s, or even two months under the HW scenario. In addition, all scenarios experience a deeper drawdown of Upper Klamath Lake (UKL) than under simulated historical conditions and show minimum elevations in October compared to November (historical). Results in Figure 5-2 show that projected mean EOM storage is less under all future scenarios than under the simulated historical reference period. This result is likely due to use of the 2013 BiOp management criteria for all scenarios. Many management decisions rely on static look-up tables, which lack the flexibility to respond to different hydrologic conditions such as changes in Upper Klamath Lake inflow timing.

17-01174_012539;17-01174_012539;17-01174_012540;17-01174_012541;17-01174_012542;17-01174_012543;1...



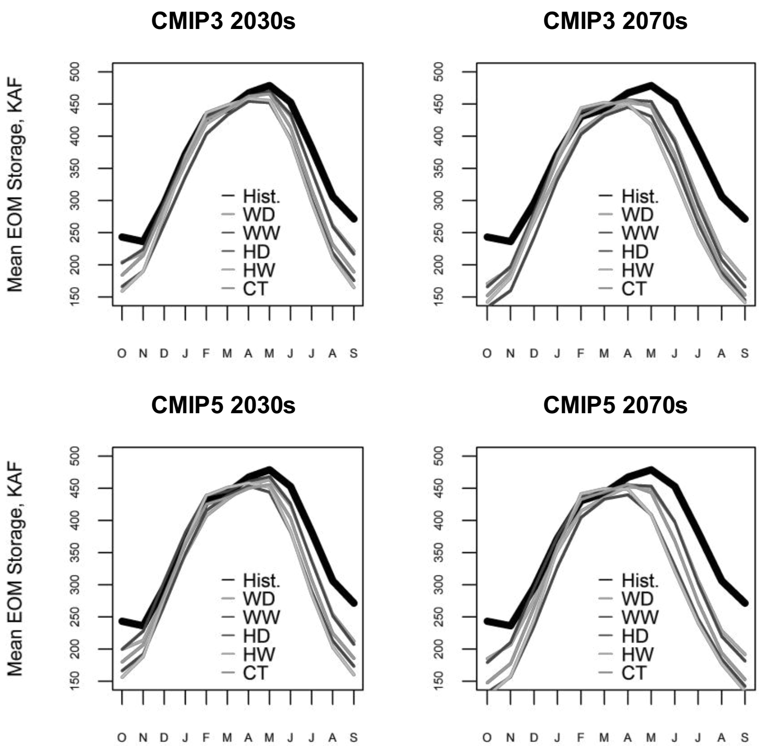



**Figure 5-2. Historical and projected future mean monthly Upper Klamath Lake storage (AF)**

### *5.4.1.2 Keno Dam Inflow*

Historical and projected future mean monthly inflow to Keno Dam is summarized in Figure 5-3. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. For the 2030s, the CT scenario indicates slightly higher peak flows while the HW and WW scenarios appear to have the highest increase in peak flow; the HD and WD scenarios show similar or slightly reduced peak flows. By the 2070s managed inflows to Keno Dam also appear to shift toward higher flows earlier in the year. Results indicate mean annual volumes increase under the wetter scenarios (HW and WW). Overall increases in Keno Dam

> **Mean Monthly Flow**
>
> Projections indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

inflow are primarily driven by increases in inflows to Upper Klamath Lake and thereby increases in Link River Dam outflows.

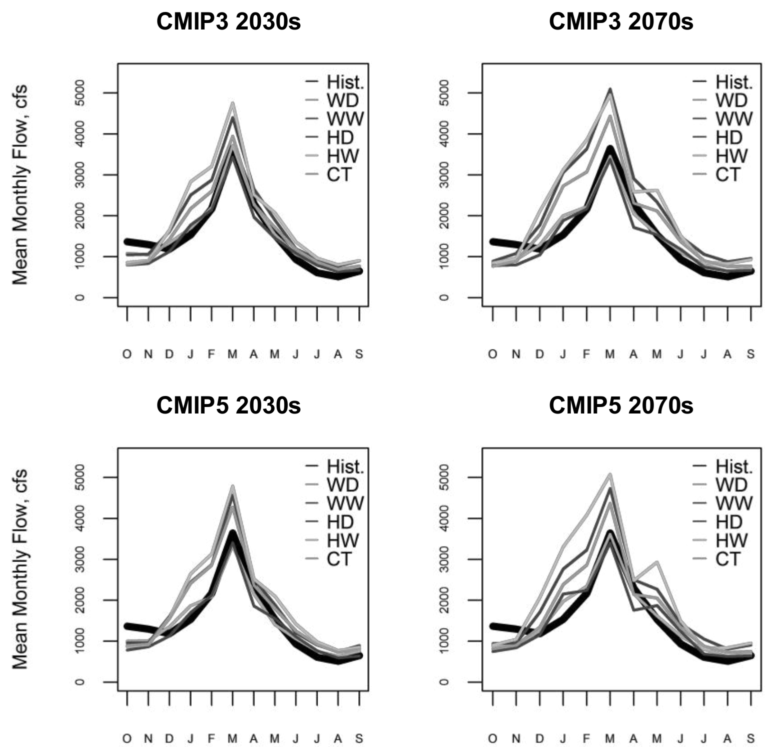



**Figure 5-3. Historical and projected future mean monthly managed inflows to Keno Dam (cfs)**

### *5.4.1.3 Iron Gate Reservoir Storage*

Historical and projected future mean monthly Iron Gate Reservoir storage is summarized in Figure 5-4. Historically, EOM reservoir storage would peak in March and have its lowest storage in the summer months. Reservoir storage historically did not fluctuate substantially through the year, generally varying between about 55,000 acre-feet and almost 57,000 acre-feet. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase; none of the climate change scenarios indicate a reduction in peak reservoir storage.

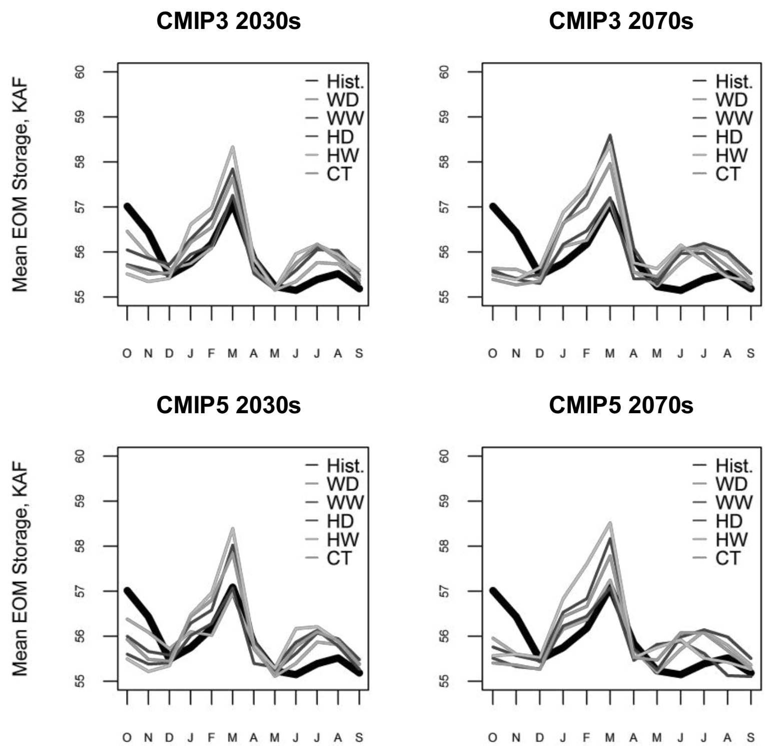



**Figure 5-4. Historical and projected future mean monthly Iron Gate Reservoir storage (KAF)**

#### *5.4.1.4 Iron Gate Reservoir Outflow*

Historical and projected future mean monthly outflow from Iron Gate Dam is summarized in Figure 5-5. Historically, mean monthly managed inflows peak in March while the lowest flows occur in August. Historical and projected changes in outflow at Iron Gate Dam correspond with those found at Keno, primarily due to their conjunctive management under the 2013 Proposed Action for Klamath Project operations. Projected changes in peak outflow are similar to Keno inflow in that the WW and the HW scenarios suggest the greatest increases. Also, particularly for the 2070s, substantial increases in flow during the months of January and February are projected. Differences between mean monthly inflows at Keno and outflow at Iron Gate from about May through September, namely projected increases at Keno and projected decreases at Iron Gate, are due to a combination of operating criteria and hydrology. Local inflows between Keno and Iron Gate are projected to decrease, which may contribute to the differences

during this period. Also during these months environmental flow requirements often govern operations, and these requirements are generally accounted for at Iron Gate Dam to maintain minimum flows. These operating criteria may result in differences in projected flows at the two locations.

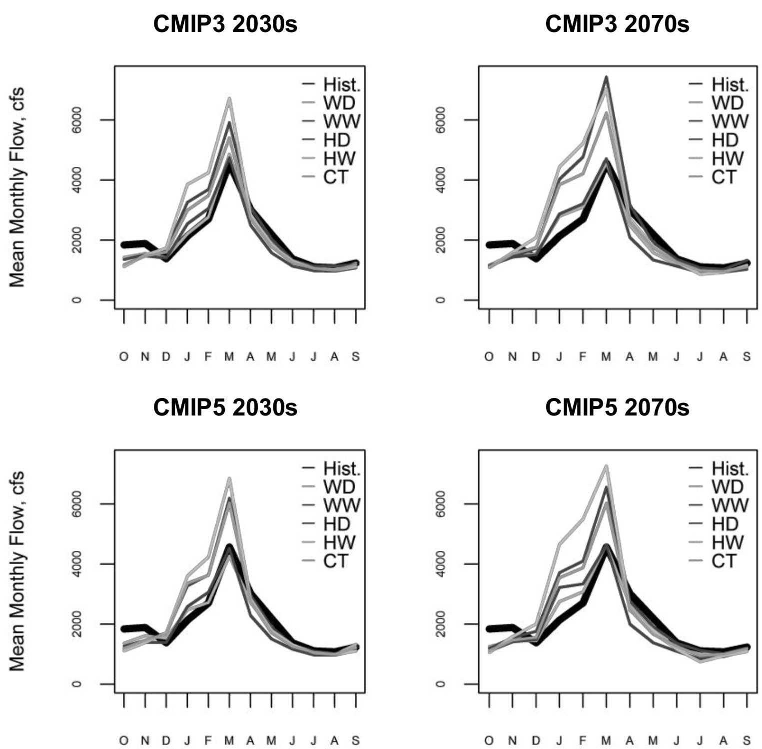



**Figure 5-5. Historical and projected future mean monthly Iron Gate Reservoir outflow (cfs)**

#### *5.4.1.5 Shasta River Flow*

Historical and projected future mean monthly flows in the Shasta River near Yreka are presented in Figure 5-6. Historical mean monthly flows exhibit a double peak, in January and again in March, the first corresponding with the period of seasonal peak rainfall and the second corresponding with snowmelt. The lowest flows occur during August. Projections of climate change indicate a range of increased snowmelt runoff contributing to streamflow (HW and WW scenarios) to decreased snowmelt runoff for the drier scenarios (HD and WD), with the central tendency similar or slightly less than historical. Flows during the

rainfall peak period are projected to increase for all but the WD scenario for the 2030s time period. By the 2070s, all scenarios project increased rainfall-driven peak flow in January. In addition, all but the WW scenario indicate reduced late spring flows, likely due to decreased snowpack (except for Mount Shasta, which is projected to experience increased snowpack due to increased precipitation and high elevations).

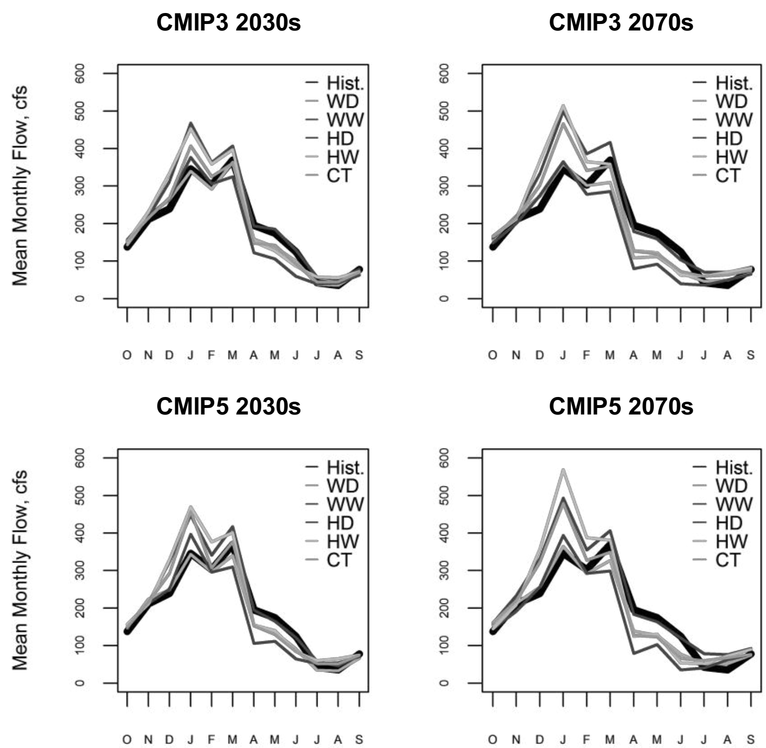



**Figure 5-6. Historical and projected future mean monthly flow in the Shasta River near Yreka (cfs)**

#### *5.4.1.6 Scott River Flow*

Historical and projected future mean monthly flows in the Scott River near Fort Jones are presented in Figure 5-7. The Scott River is a more rain-dominated watershed than the neighboring Shasta River watershed to the east. Historical mean monthly flows reflect a mixture of rain and snow during winter and early spring months, with seasonal peak flows occurring in March but closely followed by January and February. Climate change projections for both the 2030s and 2070s time periods, for both CMIP3 and CMIP5 based projections, indicate increased winter flows as a result of corresponding projected increases in precipitation. Also, the snowmelt runoff contribution to flow in the late spring months is projected to decrease.

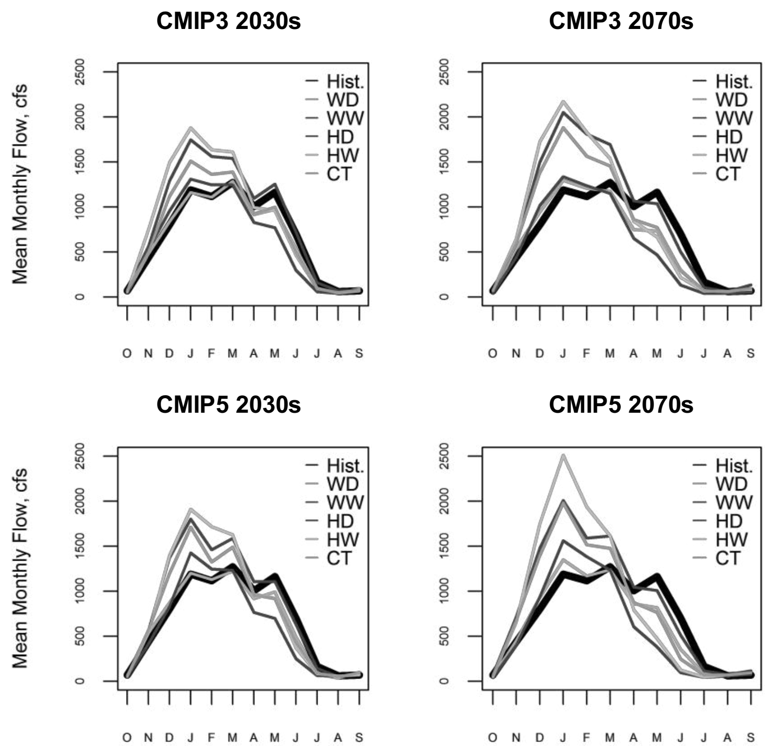



**Figure 5-7. Historical and projected future mean monthly flow in the Scott River near Fort Jones (cfs)**

***5.4.1.7 Flow at Klamath River near Orleans***

Historical and projected future mean monthly flows in the Klamath River near Orleans are presented in Figure 5-8. Managed flow in the Klamath River at Orleans reflects Upper Klamath Basin management and the contribution of tributary flows upstream of the Trinity River confluence. Historical mean monthly flows have a primary peak in March as a result of snowmelt runoff and a secondary peak in January as a result of winter rainfall. Projections of future conditions indicate increased peak flows for all scenarios, with the driest scenarios (HD and WD) similar in magnitude to historical. For the 2070s, a projected shift in the peak flow to earlier in the year corresponds with the reduced influence of snowmelt runoff as the climate warms and snowpack declines.

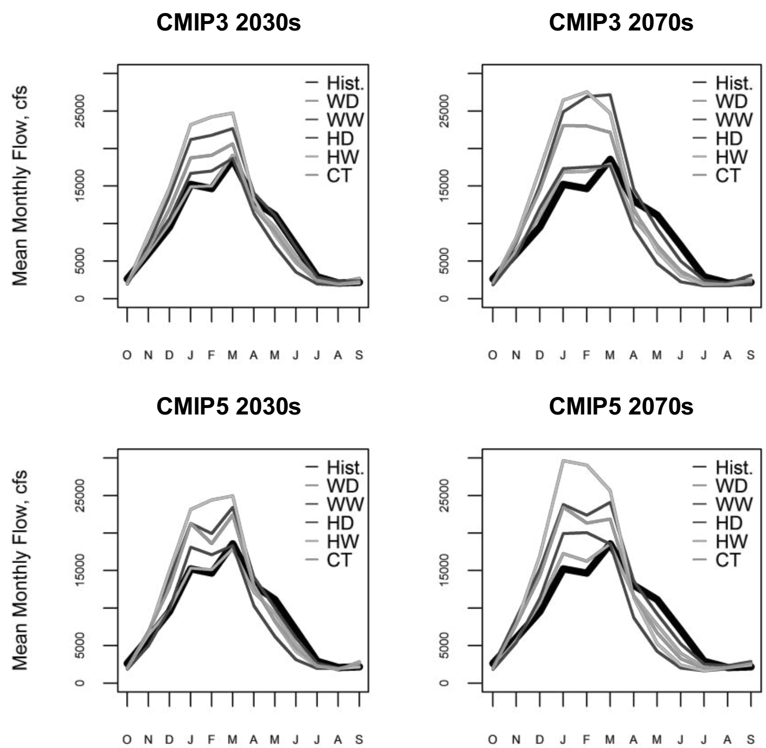



**Figure 5-8. Historical and projected future mean monthly flow in the Klamath River near Orleans (cfs)**

#### *5.4.1.8 Flow at Klamath River near Klamath*

Historical and projected future mean monthly flows in the Klamath River near Klamath are presented in Figure 5-9. Simulated flows in the Klamath River at Klamath integrate managed flows in all of the Klamath River Basin, including contributions from the Trinity River which are affected by Central Valley Project exports to the Sacramento River Basin. Historical mean monthly flows at this location exhibit a double peak in January and March corresponding with rainfall and snowmelt runoff, respectively. Projected changes in mean monthly flows for all but the driest climate change scenarios for the 2030s indicate a shift toward a more rain dominated basin, with peak flows occurring January. Interestingly, projected mean monthly flows at Orleans (Figure 5-8) do not show the same shift, corresponding with a greater increase in January flows in the Trinity River, whose confluence with the mainstem Klamath River is located between Orleans and Klamath. This may be due to the methods used to develop Trinity River flows; Trinity and Lewiston reservoirs were not explicitly modeled and instead adjusted outflows were used as input to RiverWare based on relationships between simulated natural flows (developed in Chapter 3) and historical gage records.

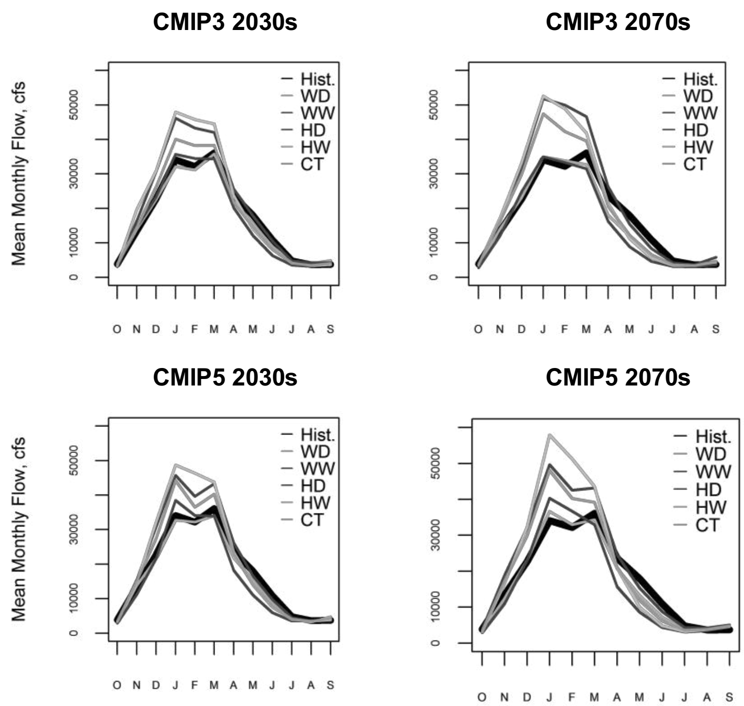



**Figure 5-9. Historical and projected future mean monthly flow in the Klamath River near Klamath (cfs)**

#### *5.4.1.9 Klamath River Water Temperature*

Historical and projected future mean monthly temperatures in the Klamath River near Klamath, as simulated by the RBM10 model, are presented in Figure 5-10. Historical water temperatures are at their maximum in August and at their minimum in January. Water temperature is projected to increase under all climate change scenarios considered by the study for both CMIP3- and CMIP5-based projections, and for both future time periods. Water temperatures historically are not favorable for salmon and projected increases in temperature exacerbate this issue.

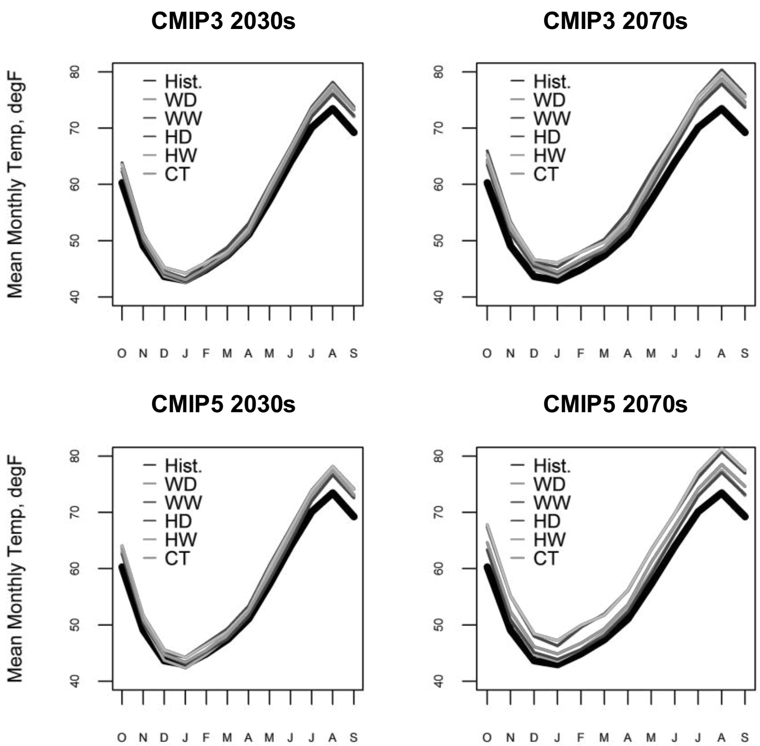



**Figure 5-10. Historical and projected future mean monthly water temperature in the Klamath River (degrees F)**

### 5.4.2 Analysis of Impacts – Ability to Deliver Water

To evaluate the ability of the Klamath River Basin to supply water to meet human needs, this study focuses on four measures: the percent of full irrigation water supply to the Klamath Project (from April through September), the mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow, mean annual flows in the Shasta River near Yreka, and mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

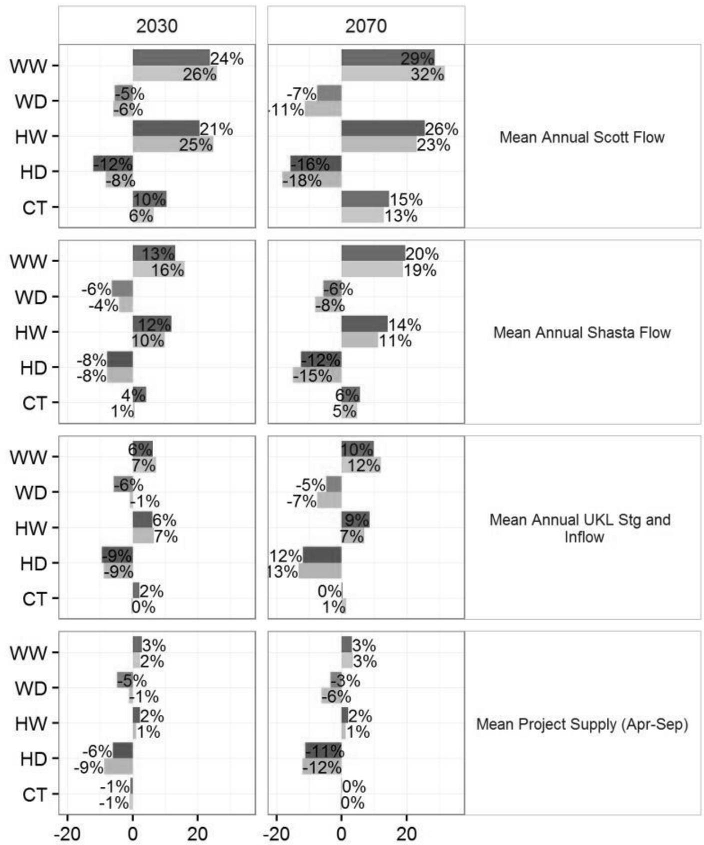
Water supply measures under simulated historical conditions are provided in Table 5-6, while projected changes in these measures are illustrated in Figure 5-11. Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the simulation period, the sum of end-of February storage plus March–September inflows at Upper Klamath Lake (another indicator of total available supply from Upper Klamath Lake) was about 1.38 million acre-feet. Additional measures representing the total water supplies in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

**Projected Klamath Project Supply**

Klamath Project irrigation deliveries average about 93 percent of full supply under historical hydrology according to simulations by the Klamath Basin RiverWare Model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

**Table 5-6. Historical measures related to water supply.**

| Measure | Historical Value | Units |
|---|---|---|
| Mean Klamath Project supply | 361.3 | KAF |
| Mean annual UKL seasonal supply | 1,378 | KAF |
| Mean annual Shasta flow | 187.7 | cfs |
| Mean annual Scott flow | 668.8 | cfs |




Notes: Changes are represented as percentages; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-11. Projected changes in water supply measures**

In terms of the projected changes in water supply measures shown in Figure 5-11, projected changes in mean annual flow in the Scott and Shasta Rivers include increases for the wetter scenarios (WW and HW) close to about 20 percent for the 2030s and 30 percent for the 2070s and decreases for the drier scenarios (WD and HD) of less than 10 percent for the 2030s and 10 to 20 percent for the 2070s, with a central tendency scenario showing more modest increases than the wetter scenarios. For mean Upper Klamath Lake supply (end-of-February storage plus March-September inflow), again the wetter scenarios indicate projected increases, with greater increases for the 2070s, while drier scenarios indicate decreases. Similar results are shown for mean Klamath Project supply from April through

September. Percent change in Upper Klamath Lake supply and Klamath Project supply (the bottom two measures listed in Figure 5-11) is computed based on projected and historical simulated values under the 2013 BiOp management criteria. No consistent differences are apparent in comparing CMIP3- and CMIP5-based scenarios. However, together they provide comprehensive information on the projected range of changes in these water delivery measures. Table 5-6 summarizes the data behind Figure 5-11.

### 5.4.3 Analysis of Impacts – Hydroelectric Power

To evaluate historical conditions and impacts of climate change on hydroelectric power production, the study focuses on the following measures: mean annual hydropower production (summed over J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities); mean annual spill volumes at J.C. Boyle, COPCO 1, and Iron Gate dams; and mean spill days per year at the same three dams. Measures are computed using results from the Klamath Basin RiverWare model.

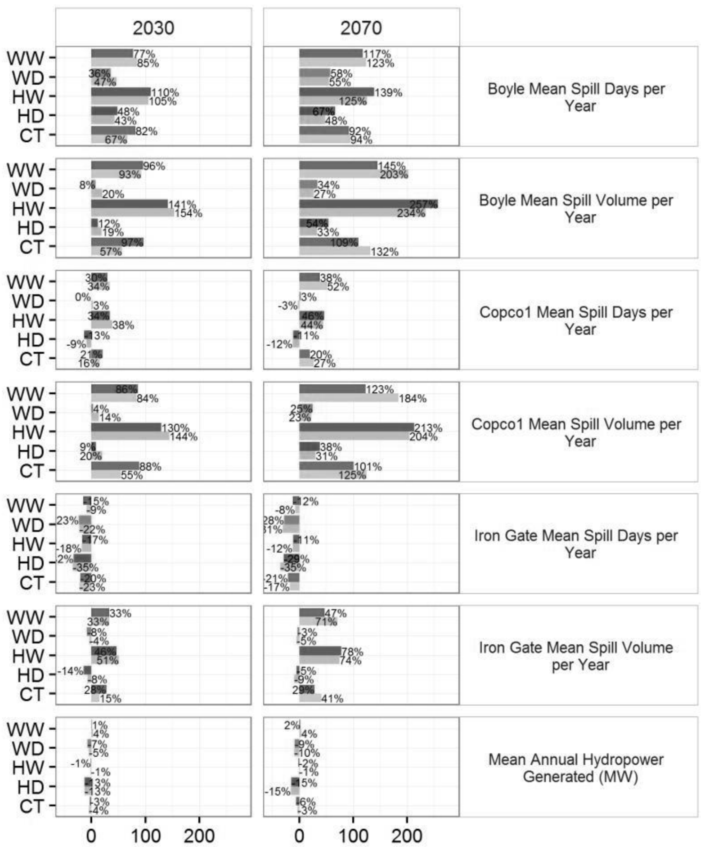
Historical hydropower measures are provided in Table 5-7, while projected changes in these measures are illustrated in Figure 5-12. Note that mean annual days with spill at the three facilities over the historical simulation period are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate.

**Projected Hydropower Production**

Hydropower production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. For all facilities, under almost all scenarios, frequency and volume of spill is likely to increase.

**Table 5-7. Historical measures related to hydroelectric power**

| Measure | Historical Value | Units |
|---|---|---|
| Mean annual hydropower generated (MW) | 26,741 | MW |
| J.C. Boyle mean spill volume per year | 163.0 | KAF |
| COPCO 1 mean spill volume per year | 186.4 | KAF |
| Iron Gate mean spill volume per year | 533.9 | KAF |
| J.C. Boyle mean spill days per year | 105.9 | days |
| COPCO 1 mean spill days per year | 42.8 | days |
| Iron Gate mean spill days per year | 170.3 | days |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-12. Projected changes in hydropower measures**

Figure 5-12 illustrates the percent change in identified hydroelectric power measures. Consistent with results discussed for basin-wide response variables, namely increased seasonal peak flows, the number of spill days and the mean annual spill volumes are projected to increase for most scenarios for both future time horizons. However, at Iron Gate the projected changes in spill volume are generally increasing, while the projected change in the mean number of spill days per year is less substantially decreasing. Projected mean number of spill days at J.C. Boyle and COPCO1 are generally increasing, while generally decreasing at Iron Gate. This result may be due to the fact that Iron Gate Reservoir has greater storage and is therefore better able to absorb high inflows than J.C. Boyle or

COPCO1. Also, the management criteria allow inclusion of a rule to avoid spill at Iron Gate, but not at J.C. Boyle or COPCO1, due in part to the need to meet environmental flow requirements.

Also, projected changes in mean annual hydropower production are much smaller on a percentage basis than the other measures, with the wetter scenarios indicating increases, the drier scenarios indicating decreases, and the central tendency scenario indicating minimal increases. Changes are between +4 percent and -13 percent for the 2030s and between +4 percent and -15 percent for the 2070s. Appendix D, Table D-12 summarizes the data behind Figure 5-12.

> **Recreation**
>
> The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

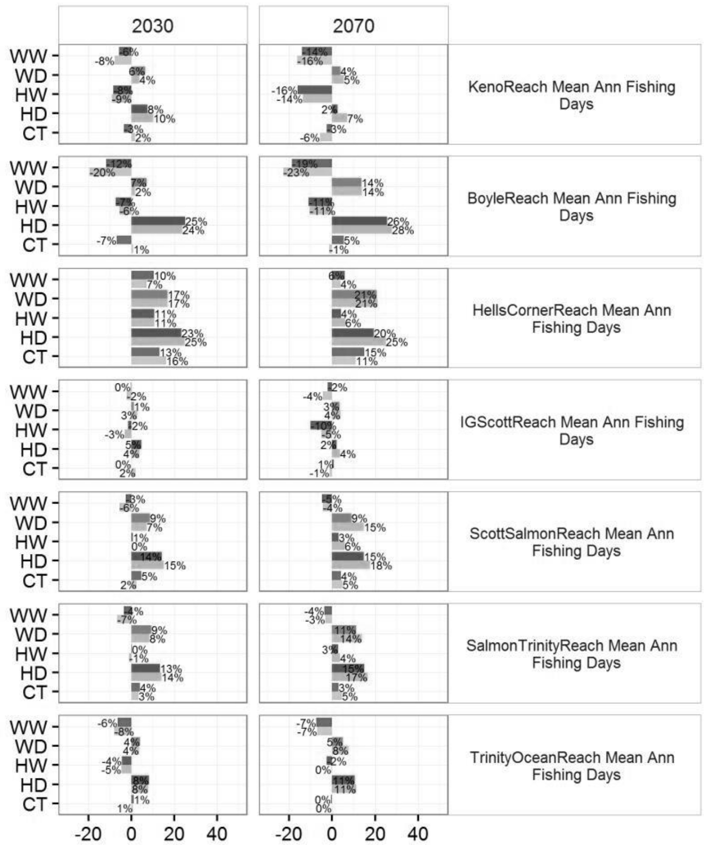
### 5.4.4 Analysis of Impacts – Recreation

Recreational measures in the Klamath River Basin are summarized for two main categories, fishing recreation and river boating recreation. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in select Klamath River reaches fall within the recommended range for each activity. Measures are computed using results from the Klamath Basin RiverWare model.

Table 5-8 provides historical recreation measures for fishing and river boating, while projected changes in these measures are illustrated in Figure 5-13 (for fishing) and Figure 5-14 (for river boating). For the historical period, in general more days fall within the recommended range for fishing than for river boating.

**Table 5-8. Historical measures related to fishing recreation**

| Measure | Historical Value | Units |
|---|---|---|
| Keno Reach mean annual fishing days | 248 | days |
| Boyle Reach mean annual fishing days | 155 | days |
| Hells Corner Reach mean annual fishing days | 220 | days |
| IG Scott Reach mean annual fishing days | 275 | days |
| Scott Salmon Reach mean annual fishing days | 184 | days |
| Salmon Trinity Reach mean annual fishing days | 214 | days |
| Trinity Ocean Reach mean annual fishing days | 253 | days |
| Keno Reach mean annual boating days | 172 | days |
| Boyle Reach mean annual boating days | 59 | days |
| Hells Corner Reach mean annual boating days | 256 | days |
| IG Scott Reach mean annual boating days | 275 | days |
| Scott Salmon Reach mean annual boating days | 249 | days |
| Salmon Trinity Reach mean annual boating days | 214 | days |
| Trinity Ocean Reach mean annual boating days | 253 | days |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-13. Projected changes in fishing recreation**

For fishing recreation, the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios (WW and HW) indicate decreases in the number of fishing days for both future time horizons. Recommended flows for fishing are generally less than for boating, and overall projections of greater future flow volumes in the basin correspond with projected decreases in fishing days. The central tendency scenario indicates modest decreases in some reaches and modest increases in other reaches. Generally, the direction of change (increase or decrease) is consistent for both future time horizons within a given reach (except J.C. Boyle reach and Trinity Ocean reach). For some scenarios and measures, CMIP3-based projections indicate greater

change, while for others they may indicate smaller change. There is no consistency between CMIP3- and CMIP5-based projections in terms of projected change across scenarios or measures.


Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-14. Projected changes in river boating recreation measures**

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. For instance, in the J.C. Boyle and Hells Corner reaches (from J.C. Boyle to COPCO 1) almost all scenarios indicate a decrease in the number of river boating days as a result of climate change, with the exception of the WW scenario for CMIP3 and the CT scenario for CMIP5. For the other reaches downstream of Iron Gate, the wetter

scenarios (WW and HW) generally indicate a reduction in the number of river boating days, while the drier scenarios (WD and HD) indicate increases in the number of river boating days (although not consistent for all measures). The CT scenario for those reaches below Iron Gate indicates modest changes (increases for most of those reaches). Note that the boating recreation measures do not account for the ability to release flows from J.C. Boyle to assure a suitable boating recreation flow range.

### 5.4.5 Analysis of Impacts – Ecological Resources

Measures related to ecological resources in the Klamath River Basin primarily concern fish and wildlife habitat and applicable species listed under ESA. Historical conditions and climate change impacts are evaluated by computing the mean annual number of days where flows in the Scott and Shasta Rivers meet or exceed recommended flow thresholds for dry year conditions by McBain and Trush (2014). Note that the target flows were developed for the Shasta River and the same targets were applied to the Scott River, though the Scott River generally has greater flow volume. For this reason, the historical frequency of meeting flow targets in the Scott River is much higher than in the Shasta River. However, the dry year targets are not met 100 percent of the time in the Scott River.

Historical conditions and climate change impacts are also measured by computing watersupply to the Lower Klamath National Wildlife Refuge via Ady Canal. Measures are computed using results from the Klamath Basin RiverWare model.

> **Ecological Resources Impacts**
>
> The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. Also, a decrease in deliveries to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

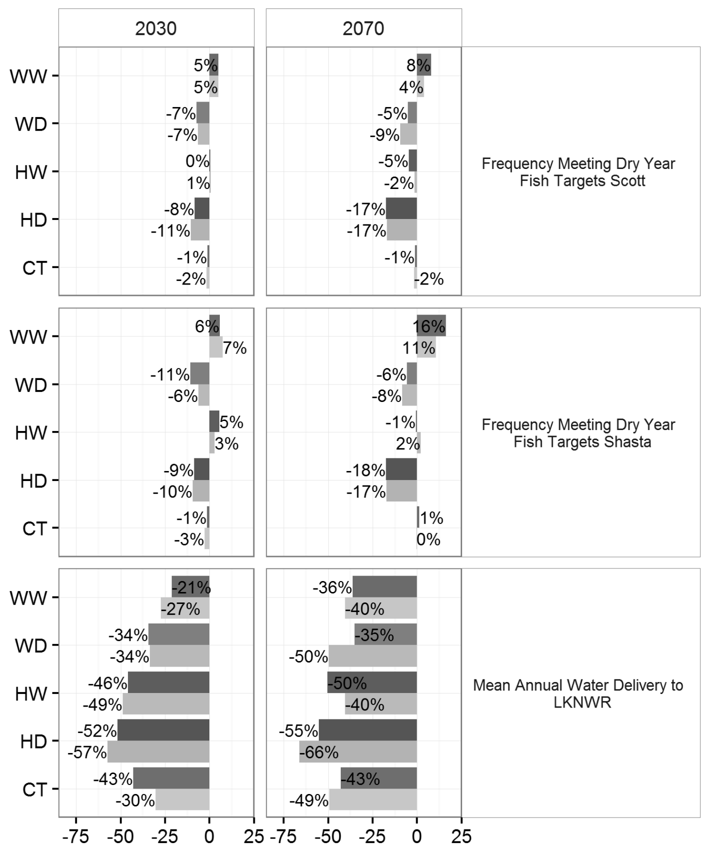
Historical measures relating to ecological benefits are provided in Table 5-9, while projected changes in these measures are illustrated in Figure 5-15. For the historical simulation period, neither dry year flow targets nor full demand at the LKNWR are met 100 percent of the time.

**Table 5-9. Historical measures related to ecological resources**

| Measure | Historical Value | Units |
|---|---|---|
| Frequency meeting dry year fish targets Scott | 70.5 | Percent of days |
| Frequency meeting dry year fish targets Shasta | 56.9 | Percent of days |
| Mean annual water delivery to LKNWR | 24.6 | KAF |

Projected changes in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers, represented as a percentage, indicate increases for

the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and HD), with greater change projected for the 2070s time horizon compared with the 2030s. CMIP3- and CMIP5-based projections are comparable, with one set of scenarios generally exhibiting more change (although not consistently one over the other). The CT scenario indicates a modest decrease in the frequency of ability to meet the dry year flow targets (i.e., negative change).




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-15. Projected changes in ecological resources measures**

Figure 5-15, illustrating the percent change in the mean annual (water year) supply to the LKNWR, shows that for all climate change scenarios there is a decrease in supply to the LKNWR, more so for the 2070s compared with the

2030s future time horizon. CMIP3- and CMIP5-based scenarios are comparable, but do show some differences. For the 2030s CT scenario, the CMIP5-based scenario indicates a reduction of about 43 percent, compared to 30 percent for the CMIP3-based CT scenario. Note that model results indicate a decrease in deliveries to LKNWR for all scenarios, while they indicate projected increases or decreases in Klamath Project supply depending on the scenario. These results may in part be explained by a projected reduction in water supply from the Lost River. Also note that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Additionally, the LKNWR is not able to take advantage of spill water under these management criteria. The resulting effect of the management criteria and projected hydrologic changes is an overall reduction in LKNWR deliveries.

Frequency of meeting minimum recommended pool elevations in Clear Lake and Gerber Reservoir were also computed as performance measures for evaluating climate change impacts. These results are not illustrated, as minimum pool elevations are met or exceeded in all climate change scenarios considered by the Basin Study. Note that climate change scenarios represent adjusted historical climates that represent the statistics of future climate for two future time horizons, the 2030s and 2070s. Therefore, potential changes in the timing and frequency of drier years and wetter years are not represented. Potential future changes in drought or wet period frequency may affect the ability of operators to maintain minimum pool elevations in Gerber Reservoir and Clear Lake.

## Water Quality Impacts

For historical hydrology conditions and all future climate scenarios, the MWAT falls within the “poor” classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

### 5.4.6 Analysis of Impacts – Water Quality

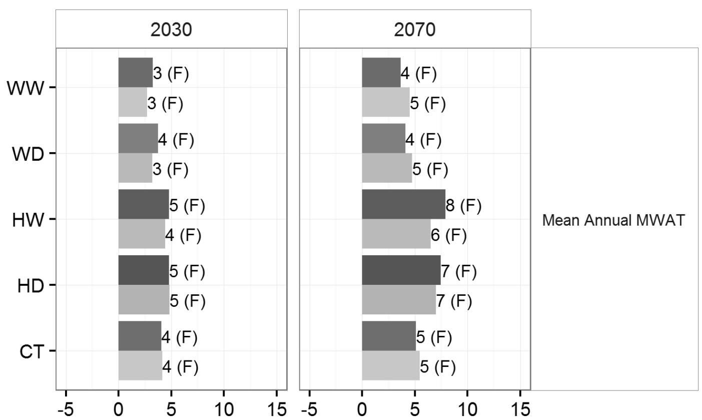
Water quality measures are presented in terms of meeting Klamath River temperature thresholds in the Klamath River near Klamath, California as recommended by the SONCC ESU salmon recovery plan (NMFS, 2012). Historical conditions and climate change impacts are evaluated by computing the mean across the simulation period of the MWAT at the Klamath River near Klamath and comparing values with those recommended in the salmon recovery plan. Analysis under historical hydrology showed that the MWAT fell within the “poor” classification for all years. Therefore, instead of reporting the frequency of the MWAT falling within the various categories ranging from “very good” to “poor,” we instead report the computed MWAT and projected change in that value, as well as the degrees F by which the “poor” classification is exceeded. The “poor” classification threshold is 63.68 degrees F, or 17.6 degrees C.

Historical measures relating to water quality are provided in Table 5-10, while projected changes in these measures are illustrated in Figure 5-16. Historically the MWAT is computed as 75.7 degrees F, which is approximately 12 degrees higher than the "poor" classification threshold for the SONCC ESU coho salmon.

**Table 5-10. Historical measures related to water quality.**

| Measure | Historical Value | Units |
|---|---|---|
| Mean annual MWAT | 75.7 | degrees F |
| Mean exceedance of MWAT – Poor | 12.1 | degrees F |

Figure 5-16 shows that for all climate change scenarios the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s. Results indicate that the temperature regime in the Klamath River is likely to become more challenging for coho salmon under warmer future climate scenarios. Identified cold water refugia and groundwater springs will continue to be critical for the survival of the species in the Klamath River Basin.




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-16. Projected changes in mean annual maximum weekly average temperature**

### 5.4.7 Analysis of Impacts – Flood Control

Flood control in the Klamath River Basin and projected changes due to a changing climate are evaluated for two types of measures: flood control releases from Upper Klamath Lake, and the date of seasonal peak flow at the major mainstem Klamath River dams (J.C. Boyle, COPCO 1, and Iron Gate). Flood control rules at Upper Klamath Lake are defined by the 2013 Proposed Action for Klamath Project Operations (Reclamation, 2012d). It is recognized that flood control measures exist for other reservoirs in the Klamath River Basin (e.g., Trinity River basin); however, due to the level of detail of the Klamath Basin RiverWare model, we focus on Upper Klamath Lake.

> **Flood Control Impacts**
>
> The frequency of Upper Klamath Lake flood control releases is projected to increase for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest increase. All scenarios project an increase in the mean annual flood control volume.

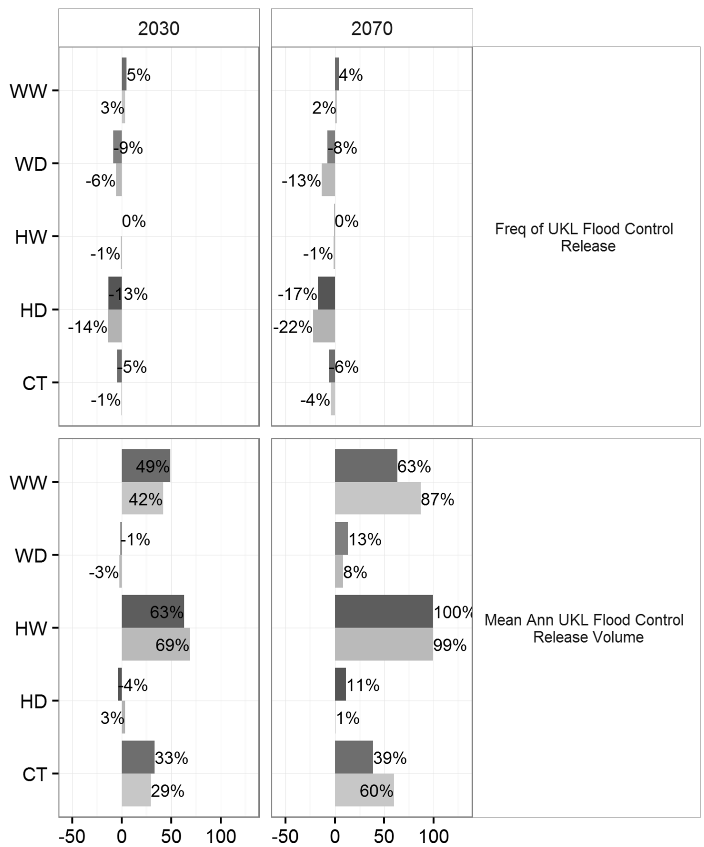
Historical recreation measures relating to flood control are provided in Table 5-11, while projected changes in these measures are illustrated in Figure 5-17. Under historical hydrology conditions, the frequency of flood control releases from Upper Klamath Lake is approximately 44 percent of days according to results from the Klamath Basin RiverWare model. The corresponding mean annual volume of flood control release water is approximately 224,000 acre-feet. Flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. The computations are consistent between the RiverWare model and the KBPM. However, it is acknowledged that the RiverWare model simulations generally indicate greater flows coming from the Lost River basin, thereby resulting in less demand by the Klamath Project for Upper Klamath Lake water, compared with the KBPM. This result may contribute to the seemingly high percentage of days of flood control release from Upper Klamath Lake. Greater flows from the Lost River basin may also explain some of the higher Keno Dam inflows in the winter time (refer to Figure 5-3). Future development of the model will further investigate these issues. The date of seasonal peak flow is the date of the center of mass of mean annual flow, or the average date by which half of the annual flow volume at the location has passed through. The historical seasonal peak flow at the three reservoirs mentioned ranges from early to mid-April.

17-01174_012539;17-01174_012539;17-01174_012540;17-01174_012541;17-01174_012542;17-01174_012543;1...



**Table 5-11. Historical measures related to flood control**

| Measure | Historical Value | Units |
|---|---|---|
| Frequency of UKL Flood Control Release | 44.1 | Percent of Days |
| Mean Ann UKL Flood Control Release Volume | 224 | KAF |
| Date of Seasonal Peak Flow at J.C. Boyle Reservoir | April 9 | Date |
| Date of Seasonal Peak Flow at COPCO 1 Reservoir | April 17 | Date |
| Date of Seasonal Peak Flow at Iron Gate Reservoir | April 15 | Date |




Notes: measures are expressed as percent change; darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 5-17. Projected changes in flood control measures**

Figure 5-17 shows that the frequency of Upper Klamath Lake flood control releases is projected to increase or change minimally for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. Again, CMIP3- and CMIP5-based projections are generally consistent. Although there is a projected decrease in the frequency of flood control releases for several scenarios, the figure also shows that all scenarios show a projected increase in the mean annual flood control volume. Further, more water is being released in the future even though the occurrence of release may be decreasing. Minimal projected change in Upper Klamath Lake flood control release, along with projected increases in spill volumes at J.C. Boyle and COPCO1 (refer to Figure 5-12), may be explained by the different ways spill is accounted for at these locations. At Upper Klamath Lake, spill is considered the volume beyond that released for Klamath Project deliveries and environmental needs, whereas at the other locations it is more simply computed as the volume above which water can be released through the power facilities. Management criteria also play a role in the differing results.

The projected change in the date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate dams ranges from little or no change to a shift toward an earlier peak by as many as 17 days (HW scenarios for CMIP3 and CMIP5 for the 2070s future time horizon). For the 2030s, the CT scenario indicates a shift toward earlier in the year by up to one week at COPCO 1 and Iron Gate, while for the 2070s the projected change for the CT scenario is about 7 to 10 days earlier. In general, projected changes in the date of seasonal peak flow at J.C. Boyle are less substantial than at the other two locations evaluated, with projected changes having ranging from 1 to 4 days later for the 2030s, and 4 days earlier to 3 days later for the 2070s depending on the scenario. Table D-13 in Appendix D summarizes the results for all scenarios and time periods.

## 5.5 Summary of Findings

This chapter evaluates the ability of the basin to meet historical and projected future water needs using a framework of models and associated measures that are used to quantify vulnerabilities. Simulations (with historical and future hydrology conditions) were performed using existing operational constraints, mainly associated with the current Proposed Action for Klamath Project operations (Reclamation, 2012d), which dictate operations throughout the Upper Klamath Basin and have implications for the river from Link River Dam to its mouth.

Performance measures for selected categories provide a basis for assessing two things: first, the ability of the modeling framework to identify and evaluate vulnerabilities to meeting the basin's water needs, and second, the ability to evaluate the impacts of climate change on the watershed. The results provide useful insights as to how climate changes, without adaptation responses, impact the Klamath Basin. The following paragraphs summarize the above analysis of managed historical and projected future conditions.

Analysis of climate change impacts using the Klamath Basin RiverWare model and USGS RBM10 water temperature model show that mean EOM storage in Upper Klamath Lake will experience earlier drawdown and a shift toward earlier maximum storage by about one month by the 2070s. For Iron Gate, EOM reservoir storage historically did not fluctuate substantially through the year. Projections for the 2030s and 2070s indicate that peak storage is likely to remain about the same or increase slightly. Projections of mean monthly managed flows at various locations throughout the study area indicate higher seasonal peak flows throughout the basin, along with a shift toward higher rainfall runoff and reduced snowmelt runoff.

Figure 5-2 showing simulated historical and projected UKL storage helps to illustrate the projected change. The simulations show historical peak storage around May. Projections indicate a shift toward earlier peak storage. In addition, the simulations indicate more flood control release (any release above Project needs and environmental requirements) in the future as well. Although none of the figures illustrate UKL inflow, it appears that Project supply is projected to decrease slightly for the drier scenarios and increase slightly for the wetter scenarios, with a small increase for the central tendency scenario. Therefore, any reduction in summer UKL inflow does not appear to affect Project supply by a large amount, on average.

Historical hydrology enables an annual average of 93 percent of full delivery to Klamath Project irrigation, according to simulations by the Klamath Basin RiverWare model, assuming a maximum supply of 390,000 acre-feet. Projections indicate modest increases in supply for the CT scenario, with increases for wetter scenarios and decreases for drier scenarios for the 2070s.

Hydropower production summed for the J.C. Boyle, COPCO 1, COPCO 2, and Iron Gate facilities has historically been about 26,800 MW, according to RiverWare model simulations. Production is projected to increase modestly under the CT scenario for the 2030s and 2070s, while wetter scenarios indicate increases and drier scenarios indicate decreases. We evaluated frequency and volume of spill at J.C. Boyle, COPCO 1, and Iron Gate dams and found that historically the dams spilled an average of 106 days at J.C. Boyle, 43 days at COPCO 1, and 170 days at Iron Gate per year. For all facilities, frequency and volume of spill is likely to increase with climate change.

Historical fishing and boating recreation in the Klamath River Basin has been strong (on the order of 155 to 275 fishing days per year and 59 to 275 river boating days per year). The central tendency scenario indicates modest decreases in fishing recreation in some reaches and modest increases in other reaches. In the J.C. Boyle and Hells Corner reaches, almost all scenarios indicate a decrease in the number of river boating days as a result of climate change.

Using flow recommendations for a dry year in the Shasta River (defined as 61 to 100 percent exceedance) from McBain and Trush (2014), we found that flow

targets were met historically on an average of 57 percent of days in the Shasta River and 71 percent of days in the Scott River (which has about three times the mean annual flow of the Shasta River). The CT scenario indicates a modest decrease in the frequency of ability to meet dry year flow targets in the Shasta and Scott Rivers. In the future, a decrease in water delivery to the LKNWR is projected for all climate change scenarios, even more so for the 2070s compared with the 2030s future time horizon.

For historical conditions and all future scenarios, the MWAT falls within the "poor" classification for all simulated years, according to the SONCC ESU coho salmon recovery plan. Further, the MWAT is projected to increase, more so for the hotter scenarios (HW and HD) and more so for the 2070s future time horizon than the 2030s.

Finally, according to the Klamath Basin RiverWare model, the historical frequency of flood control releases from Upper Klamath Lake has been about 44 percent of days, with a mean volume of about 224,000 acre-feet. The frequency of these releases is projected to increase or show little change for the wetter scenarios (WW and HW) and decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. All scenarios project an increase in the mean annual flood control volume. The date of seasonal peak flow at J.C. Boyle, COPCO 1, and Iron Gate has historically been early to mid-July, according to the model simulations. Projections of future conditions show a general shift of this peak toward earlier in the year, although the degree to which this is the case varies by scenario and location. The most modest changes are projected for J.C. Boyle (on the order of 4 days later to 3 days earlier for the 2070s). Greater shifts are projected for COPCO 1 and Iron Gate, on the order of 1 day later to 9 days earlier for the 2030s and 2 to 16 days earlier for the 2070s.

Results of the system risk and reliability analysis support the common understanding that the Klamath River Basin has experienced difficulties in meeting the range of water needs. Projected increases in precipitation and flow volumes at many locations in the basin may reduce water supply gaps in some ways; however, greater challenges are projected for ecological resources such as fish and wildlife, as well as irrigators in the Upper Klamath Basin.

## 5.6 Uncertainties Associated with System Reliability Analysis

This section summarizes uncertainties associated with various aspects of the Klamath River Basin Study system risk and reliability analysis. The uncertainties primarily correspond to the modeling used to evaluate historical and future conditions. The modeling framework for this analysis includes development and implementation of the Klamath Basin RiverWare model, as well as implementation of the USGS RBM10 water temperature model for the mainstem Klamath River. Uncertainties associated with each of these modeling efforts are

identified and described below. Further discussion of uncertainties associated with the Klamath Basin RiverWare model will be presented as part of a separate technical report documenting the development of the model.

The Klamath Basin RiverWare model was developed as a basin-wide tool for simulating current operations under the 2012 Proposed Action for Klamath Project operations (Reclamation, 2012d). Operating rules for the Proposed Action were translated from the original modeling platform of the Klamath Basin Planning Model into RiverWare. Because the KBPM modeling platform differs from the RiverWare platform, management rules in some instances were modified to accommodate the RiverWare platform. Calibration of the RiverWare model, using historical data consistent with KBPM data, was performed to the best of our ability. However, differences persist between historical hydrology-driven model simulations using the KBPM and the RiverWare models. Model calibration will continue to be addressed in the future as the model is applied to future projects.

The USGS RBM10 water temperature model was used in its original form as part of the Basin Study. Historical inputs consistent with the Basin Study water supply and demand assessments were used as input to the RBM10 model to maintain consistency within the Basin Study. Many of these inputs differed from those used in the original implementation of the RBM10 model for the dam removal studies. As such, we employed a bias correction technique for the meteorological data so it better represented the statistics of the original model data. This also facilitated use of the model in the Basin Study because, under this methodology, it was not necessary to recalibrate parameters of the water temperature model.

Simulated managed streamflows at boundary locations used by the RBM10 model were provided by the Klamath Basin RiverWare model. Original development of the RBM10 model used USGS gage data for these boundary inputs. Historical simulated RiverWare model output was, as expected, different from the inputs for the original model. Within the RiverWare model, it was possible to experience negative or close to negative flows in certain river reaches due to river routing and the computation of reach gains. The RBM10 model cannot compute water temperature provided negative river flows, so a 5 cfs adjustment was made to simulated boundary flow for those timesteps where negative flows occurred.

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# Chapter 6
# Klamath River Basin Study
# Evaluation of System Reliability with Strategies

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# Chapter 6
# Evaluation of System Reliability with Strategies

## 6.1 Introduction

Chapter 6 presents the process that was developed and utilized to formulate and screen adaptation strategies for reducing identified gaps between water supply and demand. It also identifies the strategies carried forward for quantitative evaluation under the framework developed for the Basin Study, which is further described in Chapter 5, System Risk and Reliability Analysis. Figure 6-1 provides an overall schematic of the Basin Study approach.

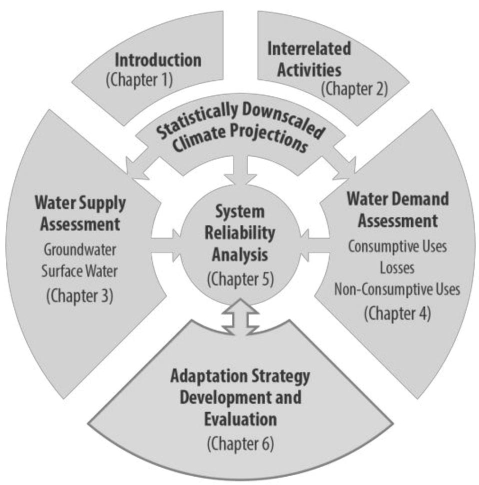



**Figure 6-1. Overall approach of Klamath River Basin Study, highlighting Chapter 6**

## 6.2 Formulation of Adaptation Strategies

The overall approach for formulating adaptation strategies to be evaluated in the Klamath River Basin Study includes the following steps:

- Identify strategies that cover a range of options.
- Organize proposed strategies in general categories based on their primary function.
- Characterize strategies based on a set of criteria to facilitate strategy screening.
- Develop representative options that allow for simplified analysis and that avoid redundancy.

Each of these approach steps is further described below.

### 6.2.1 Approach to Adaptation Strategy Identification

Adaptation strategies were identified through a comprehensive literature review of studies on climate change and water supply issues specific to the Klamath River Basin as well as studies focused on the broader Pacific Northwest. In addition to this literature review, the Basin Study team completed outreach to Klamath River Basin agency representatives, tribal representatives, stakeholders, and residents through conference calls, attendance at water supply management and planning meetings in the basin, and outreach through the Basin Study website.

The literature review effort identified 49 reports, studies, agreements, doctoral dissertations, and masters' theses completed by federal and state resource agencies, tribal natural resource departments, and university researchers. From this literature review and stakeholder input, 185 unique adaptation strategies were identified and carried forward for evaluation in the screening process described below. The full list of identified adaptation strategies is presented in Appendix E.

#### *6.2.1.1 Organization of Proposed Adaptation Strategies*

The adaptation strategies were divided into categories to facilitate a comparison of the strategies with similar approaches to addressing water supply and demand changes. These categories – increase supply, decrease demand, modify operations, and governance and implementation – are each populated with multiple strategies. This same general approach was used for the Colorado River Basin Water Supply and Demand Study (Reclamation, 2001e). The four general categories are further described below:

> ***Increase Supply:*** This category encompasses strategies that result in an anticipated increase in water supply or that identify alternative water supplies. Strategy examples include creating groundwater recharge

opportunities, increasing surface storage capacity, increasing the use of recycled water, developing conjunctive use programs, and implementing vegetation management actions.

***Decrease Demand:*** This category encompasses strategies that result in an anticipated decrease in water demand either directly or indirectly. Strategy examples include M&I water conservation (direct reduction), agricultural water conservation (direct reduction), energy water use efficiency (indirect reduction), and reductions in environmental demand (direct reduction).

***Modify Operations:*** This category encompasses strategies that involve alternative management decisions that may result in a change in water supply and/or demand. Strategy examples include improving infrastructure reliability and efficiency, reducing hillslope and/or bank erosion, improving water quality, improving preparedness for extreme events, reducing reservoir and lake evaporation, reducing out of basin transfers, improving intra-regional water transfers, or improving operational flexibility.

***Governance and Implementation:*** This category encompasses strategies that involve changes in policy, management, legal structure, or future governance issues in the Klamath River Basin. Strategy examples include improvements to public education, developing and improving partnerships between stakeholders, improving research, modifying or developing new policies, developing decision support tools, providing for habitat protection, seeking funding, implementing watershed management, and improved land use practices.

Figure 6-2 indicates the number of proposed adaptation strategies identified per category.

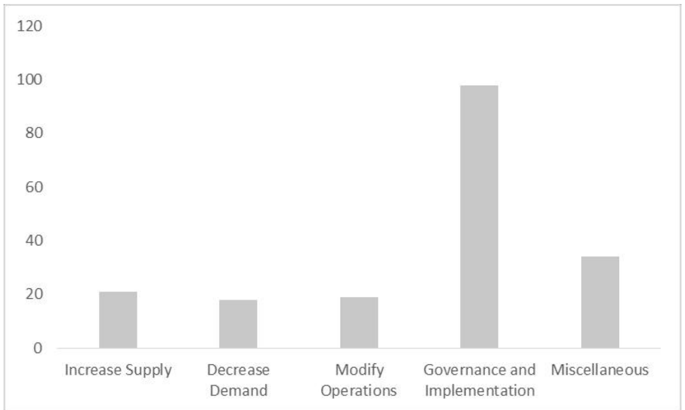



**Figure 6-2. Number of adaptation strategies identified**

#### *6.2.1.2 Criteria for Adaptation Strategy Screening*

Once the proposed strategies were organized into general function categories, they were evaluated and screened in a staged analysis effort. Evaluation measures were utilized to assess each adaptation strategy's capacity to address changes in water supply and demand. These evaluation measures were developed by Reclamation in consultation with the non-federal partners consistent with the selection criteria developed for the evaluation of options during development of the On Project Plan (Klamath Water and Power Agency, 2013). The On Project Plan screening criteria were formulated through an extensive stakeholder outreach process that resulted in wide acceptance of their use for the screening of the water conservation and efficiency, water storage, groundwater development and substitution, and demand management options identified in that planning effort. Reclamation and the non-federal partners relied on these widely accepted criteria during the development of evaluation measures for the Basin Study to incorporate the input already provided by these stakeholders.

The initial screening effort evaluated each strategy in each category to determine if it could be represented by the Basin Study models. Strategies that could be modeled could be quantitatively evaluated in this Basin Study Report; strategies that could not be modeled were evaluated qualitatively. The results of the first screening for each strategy are included in Appendix E.

Following the initial screening, the strategies that could be modeled were evaluated qualitatively, utilizing the criteria detailed below in Table 6-1, to assess the strategy's implementation risk and uncertainty, reliability, and environmental effect. Reclamation and the non-federal partners qualitatively evaluated these screening criteria, arriving at representative strategies that encompass the collective goals of the criteria, present the greatest potential for beneficial effect, and were identified as high priorities to the non-federal partners, while also involving a range of options for reducing identified vulnerabilities in the Klamath River Basin.

**Table 6-1. Description of criteria for assessing adaptation strategies**

| |
|---|
| **Provides verifiable, durable and implementable benefit to align water supply and demand for the Klamath River Basin** |
| This criterion evaluates whether a strategy is capable of providing verifiable and affordable reductions in projected water supply/demand gaps and assures all associated administrative requirements are reasonable and not overly burdensome or complex. Strategies performing well under this criterion are expected to provide a measurable water supply increase, and strategies with low ratings are anticipated to deliver minimal increases in water supply that would be difficult to verify. |
| **Consistency with legal and regulatory requirements** |
| This criterion evaluates whether a strategy is implementable with respect to compliance with all existing laws, regulations, or contracts, or requires a relatively minor revision in such requirements that would allow for implementation. Strategies that performed well under this criterion had no identified legal and regulatory issues and strategies with low ratings would require major legal or regulatory actions, like new water rights and major environmental compliance investigations. |

**Table 6-1. Description of criteria for assessing adaptation strategies**

| |
|---|
| **Affordability** |
| This criterion evaluates whether a strategy furthers the objective of aligning demand with Klamath water supply availability in a manner that is commensurate with the cost, allowing for a comparison of the relative cost of alternative strategies. This criterion was rated with high ranking strategies requiring no new costs or investment and low performing strategies requiring large capital expenditures and/or high long-term operations and maintenance costs. |
| **Flexibility** |
| This criterion evaluates whether a strategy would have, or not unduly limit, the capability to be adjustable over time. This criterion was rated with high ranking strategies allowing for implementation to be adjusted over time and low ranking strategies implementing new infrastructure that could not be moved or have its operations modified. |
| **Protection of water rights** |
| This criterion evaluates whether a strategy would result in injury to existing water rights holders. This criterion was rated with high ranking strategies producing no effect on existing water rights and low ranking strategies potentially impacting neighboring surface and groundwater availability. |
| **Environmental and third-party impacts and benefits** |
| This criterion evaluates whether a strategy would comply with applicable environmental laws and not involve unacceptable environmental impacts. This criterion was rated with high ranking strategies producing no effect on environmental resources and low ranking strategies generating adverse impacts on water quality and other resources. |

#### *6.2.1.3 Summary of Selected Adaptation Strategies*

The adaptation strategy screening process resulted in the identification of five strategy concepts that are carried forward for evaluation in the Basin Study models. This section summarizes these strategy concepts by category.

**Increase Supply**

*Additional Surface Water Storage Capacity*

This strategy concept includes quantification of potential surface storage opportunities in the Upper Klamath Basin. Some examples of proposals that fall within this strategy concept are listed in Appendix E. Additional surface water storage capacity is quantified as the incremental excess water defined in the Klamath Basin Planning Model. This excess water is quantified as the remaining water after releases are made to the Klamath Project and to meet environmental needs, including instream flow needs in the Klamath River and water stored in Upper Klamath Lake to maintain elevations. For this strategy, it is assumed that the remaining water could be stored for future use; however, it is acknowledged that the 2013 Klamath Project proposed action Biological Assessment and associated Biological Opinion consider this quantity to be part of the environmental water account.

**Decrease Demand**

*Agricultural Water Conservation*

This strategy concept includes reduction in overall agricultural water demand throughout the basin by a range of percentages (between 30 percent and 50 percent). One goal of this implemented strategy concept is to determine how

much reduced agricultural demand would be needed to offset the impacts of climate change alone. Reductions in agricultural water demand might be obtained through means identified in the proposed strategy examples listed in Appendix E. These might include canal lining and pump operation optimization; crop idling, irrigated land retirement and rain-fed agriculture; shifting agricultural production to more drought tolerant crops; and converting irrigation systems to more efficient technologies along with the use of cover crops to improve soil productivity.

*Additional Supply to Upper Klamath Lake*

This strategy concept captures the additional 30,000 acre-feet of water provided for Upper Klamath Lake in the KHSA, KBRA, and Upper Klamath Basin Comprehensive Agreement as generated by land retirement actions in the Upper Klamath Basin. The strategy concept does not identify individual areas where water demand reduction would occur. However, this strategy assumes that the additional volume of water is made available proportionally between the Sprague River, the Williamson River upstream of its confluence with the Sprague River, and the local inflows between the confluence and Upper Klamath Lake. The proportions of the total 30,000 acre-foot volume are determined based on the relative contributions to Upper Klamath Lake inflows of mean annual flow from these three sources (Sprague River, Williamson River, and local inflows between the Sprague-Williamson confluence and Upper Klamath Lake). The goal of this strategy concept is to evaluate the effect of reductions in collective water use upstream of Upper Klamath Lake. This strategy also assumes that operating rules are not modified to compensate for the additional Upper Klamath Lake inflow.

**Modify Operations**

Two strategy concept options were developed to capture the adaptation strategy articulated in the screening process as “reduce environmental demand.” These strategy concepts were developed to facilitate the analysis in the Basin Study models of five strategy examples: protect cool water refugia; keep higher quality water in-stream to protect species and river ecosystems by using lower quality water for agricultural purposes; purchase water from water-rights holders and keep that flow in-stream to reduce demand on a short-term basis; curb demand with ecosystem restoration/improvements, water use effectiveness, and environmental water scarcity programs; and ensure adequate flows for fish and wildlife habitat.

*Tributary Water Temperature Reduction*

This strategy concept addresses the need for cold water refugia in summer months to support fish and wildlife, particularly salmonids, in the Klamath River Basin tributaries. This concept is based on existing emergency water management planning in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs. In this strategy concept, a 4 degrees Celsius (degrees C) reduction in water temperature (or about 7 degrees F) in the Scott and Shasta Rivers is assumed as input to the RBM10 stream temperature model for the Klamath River, and effects of that reduction on mainstem Klamath River temperature are evaluated.

#### *6.2.1.4 Sensitivity of Simulated Water Temperature to Changes in Flow and Climate*

This strategy concept includes exploring relationships between water temperature change and streamflow change, using historical and future climate change simulations of managed streamflow (using the Klamath RiverWare planning model) and river temperature (using the RBM10 model). By evaluating potential relationships between temperature and flow change, it may be possible to estimate the needed change in flow to obtain a desired change in Klamath River temperature. Such information may be valuable in determining what changes in water management may be needed to counter the impacts of climate change.

## 6.3 Uncertainties Associated with Strategy Selection

Adaptation strategies were intended to encompass a range of management actions. They were selected to be broad in scope with basin-wide implications, and not specific to any particular subbasin or singular project operation. Broad strategy concepts were selected, in part because numerous existing studies have evaluated some proposed actions in depth, and also because management conditions in the basin are dynamic. Strategies were selected with the intent that they noticeably reduce water supply and demand imbalances; however, they were selected without prior knowledge of their relative impact. Therefore, there is uncertainty as to whether the selected strategies have greater impact on system reliability than those that were not selected. In short, there may be additional strategies that could reduce water supply and demand imbalances but were not considered by the study.

In addition, strategies were initially screened on their ability to be modeled in the framework of the Basin Study. A strategy that could not be modeled by the Basin Study framework may in fact have substantial impact on system reliability; however, the impact could not be appropriately assessed with respect to that resulting from selected strategies.

## 6.4 Evaluation of System Reliability with Adaptation Strategies

In Chapter 5, projected response to climate change is evaluated by examining effects on basin-wide response measures and on several categories of performance measures. Basin-wide response measures include flows at key locations, river temperature, UKL storage, and Project delivery. Performance measures provide additional details on operational elements such as hydropower, flood control, recreation, and ecological resources. In the analysis described in Chapter 6, the potential for adaptation strategies to affect response to climate change is evaluated. Basin-wide response measures and system performance measures are examined, comparing the collective effects of both climate change and adaptation strategies to the effects of climate change alone.

An illustration of the model scenarios that capture these differences is visualized in Figure 6-3. The baseline scenario uses historical hydrology, and in Chapter 5 we compare results from model simulations using five future climate scenarios, for both the 2030 time horizon and the 2070 time horizon, as well as CMIP3- and CMIP5-based temperature and precipitation projections. The blue line in Figure 6-3 demonstrates this comparison. In this chapter (Chapter 6), the focus is on the effects depicted by the orange line and how these differ from the baseline comparison.

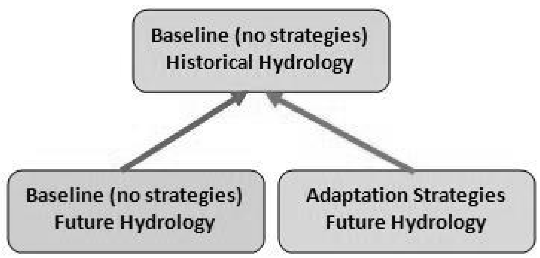



**Figure 6-3. Illustration of methodology for evaluating adaptation strategy concepts**

The following sections summarize projected changes in basin-wide response variables and system performance measures according to the baseline (i.e., with climate change scenarios but no adaptation strategy concepts) and adaptation strategy concepts previously discussed. Summary figures throughout this section illustrate changes in the strategy concepts associated with agricultural water conservation and additional supply to Upper Klamath Lake. The strategy concepts are defined as follows in the summary figures:

**Baseline** – with climate change impacts, but no adaptation strategy concepts. This is similar in concept to a no action scenario.

**Reduce ET 30% -** Reduction of agricultural demands throughout the basin by 30 percent

**Reduce ET 50% -** Reduction of agricultural demands throughout the basin by 50 percent

**Add 30KAF** – Addition of 30 KAF annually to Upper Klamath Lake inflow (contributed proportionally by Williamson River, Sprague River, and other gains, based on mean annual flow)

Results for additional strategy concepts are summarized for water quality measures. These additional strategy concepts are defined as follows in the summary figures under Section 6.4.6, Analysis of Impacts – Water Quality. Note

that this adaptation strategy concept only affects the water quality measures. Therefore, results for this measure are only summarized for these measures.

**Reduce Shasta Scott 4degC –** Reduction of Shasta and Scott River temperatures by 4 degrees C (about 7 degrees F) year round

**Add Flow 10% -** Addition of flow by 10 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

**Add Flow 20% -** Addition of flow by 20 percent to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River

**Reduce Tribs 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round in all tributaries represented in the RBM10 water temperature model. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

**Reduce Dam Outflow 4degC -** Reduction of temperatures by 4 degrees C (about 7 degrees F) year round from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River. Note that this concept may not be a realistic strategy, but it allows for evaluation of sensitivity to changes in flow and temperature.

Results for the strategy concept to quantify additional surface water storage capacity are summarized under Section 6.4.7, Analysis of Impacts – Flood Control, where the mean annual Upper Klamath Lake flood control volume is quantified and evaluated. This strategy concept does not identify any specific location for additional surface water storage; however, the location for quantifying additional water is at Upper Klamath Lake.

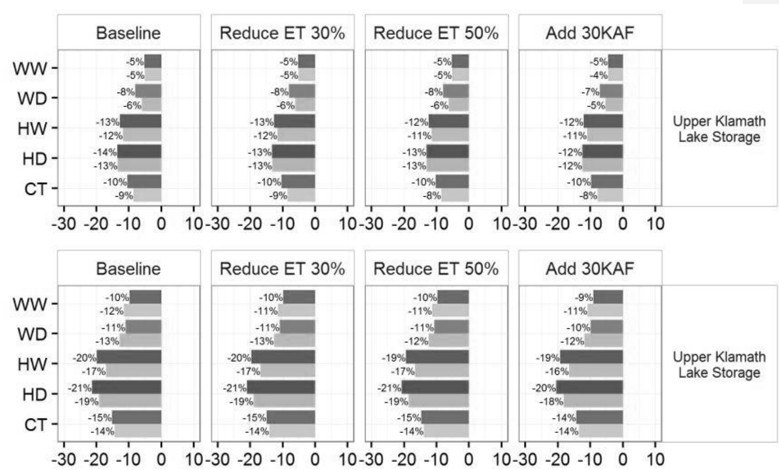
### 6.4.1 Analysis of Impacts – Basin-wide Responses

Analysis of system reliability under baseline and scenarios with adaptation strategy concepts allows for an understanding of how strategies may reduce the basin's vulnerability to climate change. Similar to Chapter 5, we explore projected change in managed river flow at various locations within the basin, as well as mainstem Klamath River stream temperature.

#### *6.4.1.1 Upper Klamath Lake Storage*

Projected changes in mean annual end of month (EOM) storage in Upper Klamath Lake under baseline and strategy scenarios are summarized in Figure 6-4. Under the baseline scenario (climate change only), mean annual storage is projected to decline under all scenarios, more so for the 2070s than for the 2030s. Neither of the strategy concepts for reducing agricultural water demand (by 30 percent and 50 percent) reduce climate change impacts substantially. Percent reductions in storage conditions are minimally affected, except for the HD climate change scenario for the 2030s and for the warmer scenarios (WW and WD) for the 2070s.

Adding 30 KAF of inflow to Upper Klamath Lake does reduce the impacts of climate change by 1 to 2 percent under all climate change scenarios for both the 2030s and 2070s. Table 6-2 summarizes projected changes in storage volume under the CT scenario for both future time periods. Implementing the Add 30KAF strategy concept results in a 26 or 33 KAF reduction in mean annual storage for the 2030s, compared to 29 or 35 KAF for the baseline for CMIP3- and CMIP5-based projections, respectively. For the 2070s, the projected reduction is 46 or 48 KAF, compared to 48 or 51 KAF for the baseline.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

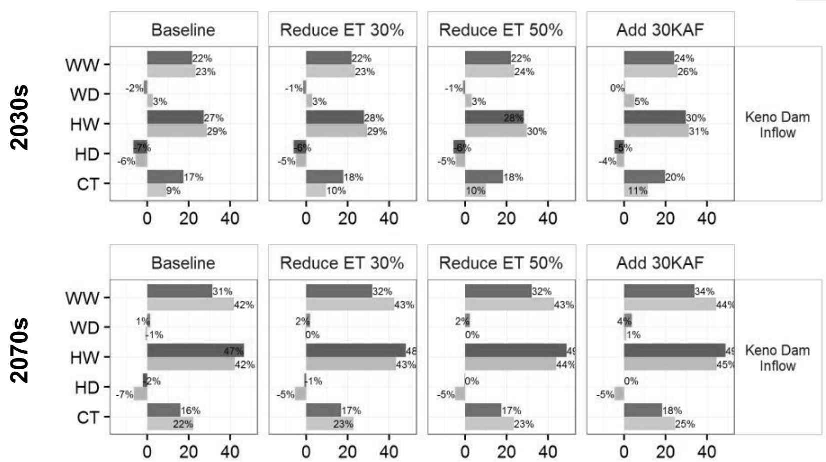
**Figure 6-4. Projected change (percent) in mean annual Upper Klamath Lake storage**

**Table 6-2. Summary of projected change in mean annual Upper Klamath Lake Storage for the Central Tendency scenario in units of KAF**

| Central Tendency Scenario | CMIP | Baseline (KAF) | Reduce ET 30% (KAF) | Reduce ET 50% (KAF) | Add 30KAF (KAF) |
|---|---|---|---|---|---|
| Historical | | 337 | | | |
| 2030 | CMIP3 | -29 | -29 | -28 | -26 |
| | CMIP5 | -35 | -35 | -34 | -33 |
| 2070 | CMIP3 | -48 | -47 | -47 | -46 |
| | CMIP5 | -51 | -50 | -50 | -48 |

#### *6.4.1.2 Keno Dam Inflow*

Projected changes in mean annual inflow to Keno Dam under baseline and strategy scenarios are summarized in Figure 6-5. Under the baseline scenario (climate change only), mean annual inflow is projected to increase under the wetter scenarios (WW and HW) for both future time periods and decrease modestly under the drier scenarios (WD and HD), with an increase under the CT scenario projected to be 9 or 17 percent for the 2030s and 16 or 22 percent for the 2070s, depending on consideration of CMIP3- or CMIP5-based projections. Implementation of each of the strategy concepts would maintain or increase the mean annual inflow at Keno, and by similar percentages. Addition of 30 KAF of inflow to Upper Klamath Lake appears to have a larger effect on Keno inflow than does reduction in agricultural demands in the regions upstream of Keno.



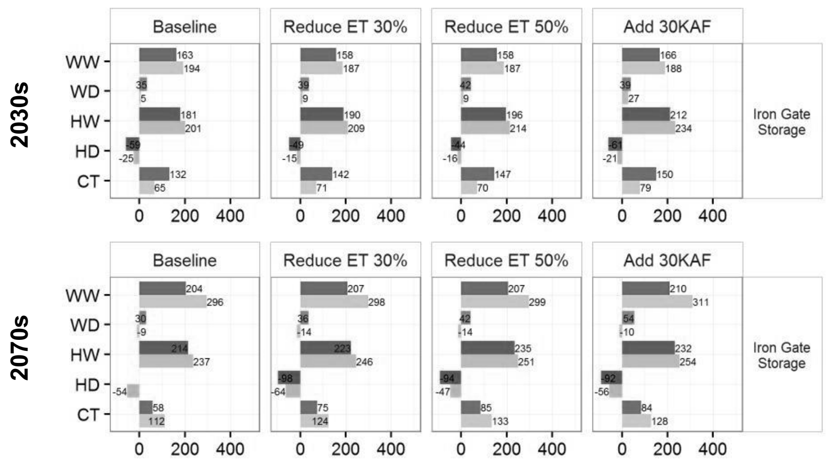

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-5. Projected change (percent) in mean annual inflow to Keno Dam**

#### *6.4.1.3 Iron Gate Reservoir Storage*

Projected changes in mean annual Iron Gate Reservoir storage under baseline and strategy scenarios are summarized in Figure 6-6. Under the baseline scenario (climate change only), mean annual storage is projected to change very little on a percentage basis compared with the historical simulation. Iron Gate Reservoir elevations have not fluctuated much historically, typically staying between 55,000 acre-feet and 57,000 acre-feet. Projected changes shown in Figure 6-6 are reported in units of acre-feet. Mean annual storage is projected to increase under all scenarios and strategies, with the exception of the HD scenario for both the 2030s and 2070s time periods. Reduction of agricultural demand provides some additional storage at Iron Gate, but generally the addition of 30 KAF inflow to Upper Klamath Lake has a larger impact on Iron Gate storage. Still, all

adaptation strategy concepts do not substantially change Iron Gate storage and do not generally counter the effects of climate change.

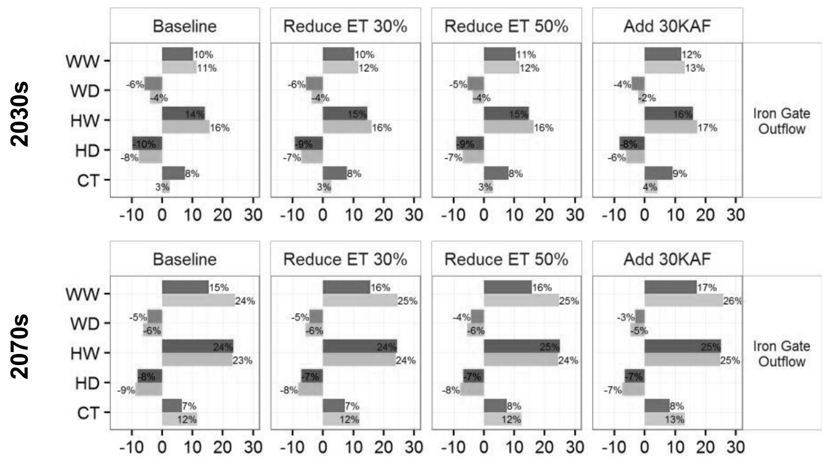



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-6. Projected change (acre-feet) in mean annual Iron Gate Reservoir storage**

#### *6.4.1.4 Iron Gate Reservoir Outflow*

Projected changes in mean annual Iron Gate Reservoir outflow under baseline and strategy scenarios are summarized in Figure 6-7. Under the baseline scenario (climate change only), mean annual outflow is projected to increase under wetter scenarios (WW and HW) and decrease modestly under drier scenarios (WD and HD), with the CT scenario indicating increases of 3 or 8 percent for the 2030s and 7 or 12 percent for the 2070s. Implementation of adaptation strategies does not substantially counter climate change impacts. Reduction of agricultural demand increases the effect of additional outflow at Iron Gate, but only by about one percent for most climate change scenarios considered. Additional inflow to Upper Klamath Lake (Add 30KAF) increases the additional outflow at Iron Gate by up to 2 percent over the baseline response to climate change alone.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-7. Projected change (percent) in mean annual inflow to Iron Gate Reservoir.**

#### *6.4.1.5 Shasta River Flow*

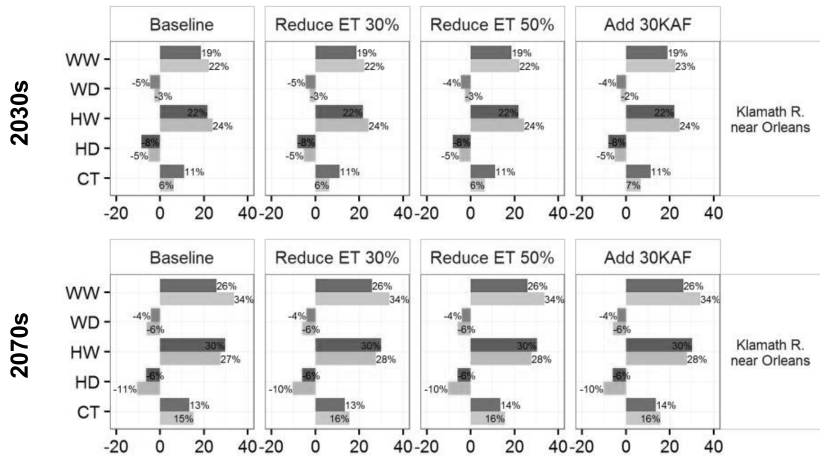
Projected changes in mean annual flow in the Shasta River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

#### *6.4.1.6 Scott River Flow*

Projected changes in mean annual flow in the Scott River are discussed in Section 6.4.2, Ability to Deliver Water, because this was selected as a measure of system reliability.

#### *6.4.1.7 Flow at Klamath River near Orleans*

Projected change in mean annual flows in the Klamath River near Orleans under baseline and strategy scenarios is summarized in Figure 6-8. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 6 or 11 percent for the 2030s and 13 or 15 percent for the 2070s, according to model simulations. Similar to other upstream locations, reduction of agricultural demand in the contributing area to the basin upstream of Orleans results in no change for the 2030s and little change for the 2070s in simulated managed flow on a percentage basis. Additional Upper Klamath Lake inflow of 30 KAF annually has only a slightly greater impact than agricultural demand reduction.

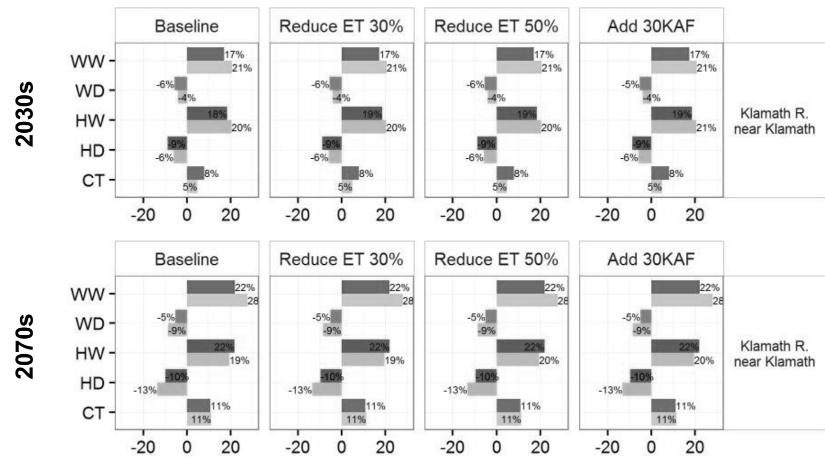


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-8. Projected change (percent) in mean annual flow at Klamath River near Orleans**

#### *6.4.1.8 Flow at Klamath River near Klamath*

Projected changes in mean annual flows in the Klamath River near Klamath under baseline and strategy scenarios are summarized in Figure 6-9. Under the baseline scenario (climate change only), mean annual outflow is projected to increase for the wetter scenarios (WW and HW), decrease modestly for the drier scenarios (WD and HD), and increase for the CT scenario by 5 or 8 percent for the 2030s and 11 percent for the 2070s, according to model simulations. Generally, the adaptation strategies either have no influence or increase flows on a mean annual basis, about one percent or less for the 2030s and no noticeable change for the 2070s. This result is in part due to the fact that any change in flow volume is a small percentage of the overall river flow at Klamath, which is close to the mouth of the basin.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-9. Projected change (percent) in mean annual flow at Klamath River near Klamath**

### 6.4.2 Analysis of Impacts – Ability to Deliver Water

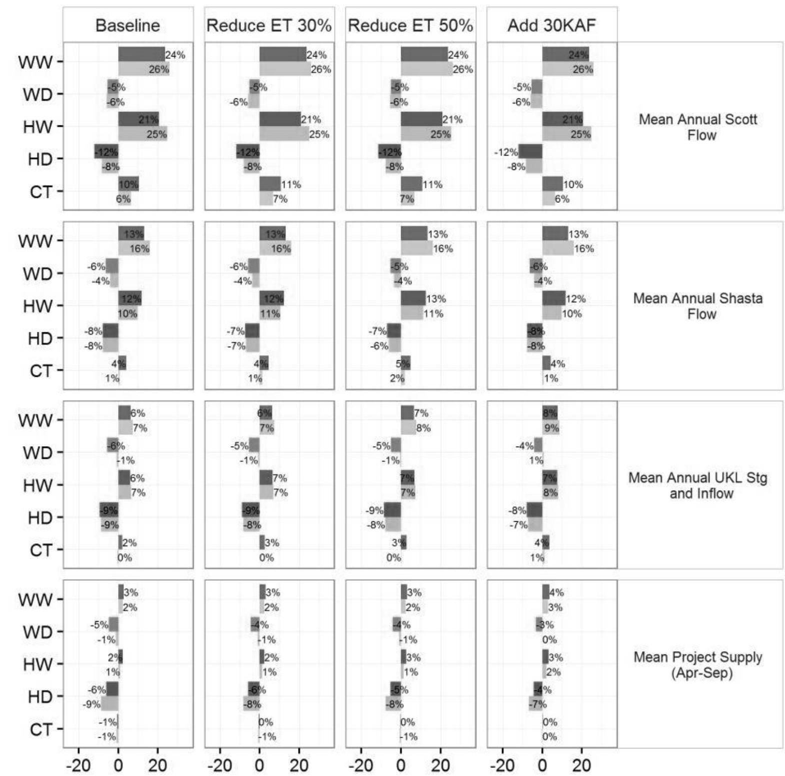
As discussed in Chapter 5, measures of the ability of the Klamath River Basin to supply water to meet human needs include (1) the April through September irrigation water supply to the Klamath Project (Project Supply), (2) mean annual sum of end-of-February Upper Klamath Lake storage plus actual March through September Upper Klamath Lake inflow (Upper Klamath Lake Supply), (3) mean annual flows in the Shasta River near Yreka, and (4) mean annual flows in the Scott River near Fort Jones. Measures are computed using results from the Klamath Basin RiverWare model.

Results from the historical baseline simulation over water years 1970–1999 show that historical hydrology enables an annual average of 93 percent of full Klamath Project irrigation supply under current operating criteria, assuming a maximum supply of 390,000 acre-feet. Results also show that, on average over the historical simulation period, the Upper Klamath Lake Supply parameter was about 1.38 million acre-feet. Additional measures representing the overall hydrology conditions in Shasta and Scott Rivers (subtracting out irrigation demands) are about 188 cfs and 669 cfs, respectively.

Projected changes in water supply measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-10 and for the 2070s in Figure 6-11. For the Scott and Shasta Rivers under the baseline scenario (climate change only), mean annual flow is projected to increase under wetter scenarios (WW and HW) and decrease under drier scenarios (WD and HD), with the CT scenario indicating a modest increase. For all scenarios, projected changes are greater for the 2070s time period than for the 2030s. For both rivers, reduction of agricultural demand (by 30 or 50 percent) does not appear to provide a substantial amount of additional flow volume, as indicated by no change or small change in the percent increase or decrease of mean annual flow. As expected, additional 30 KAF of inflow to Upper Klamath Lake does not impact mean annual flow in these rivers.

## Projected Klamath Project Supply

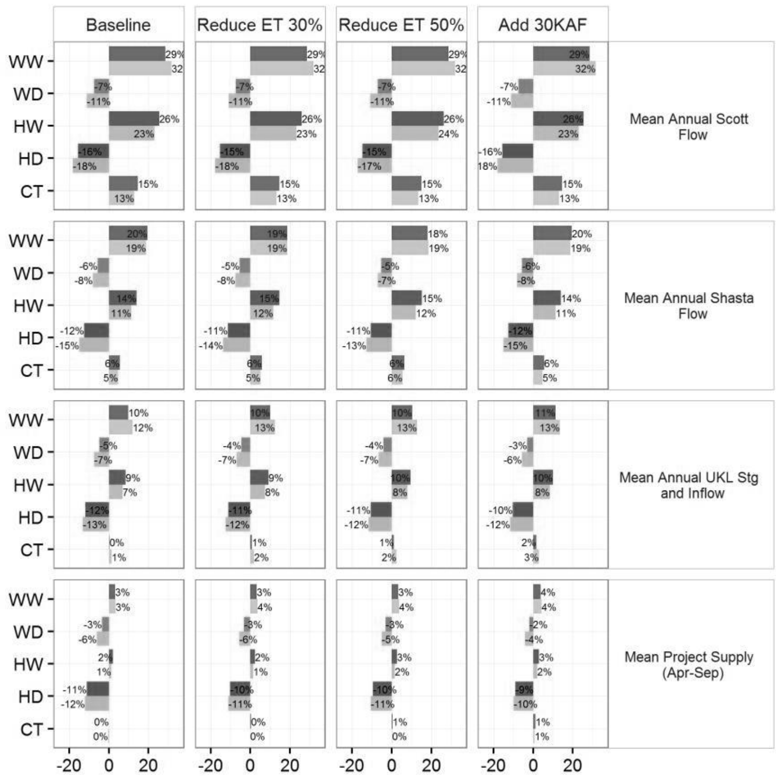
Neither reduction of agricultural demands nor additional 30 KAF inflow to Upper Klamath Lake have substantial impacts on mean Klamath Project water supply (April – September). However, the additional 30 KAF inflow does provides slightly greater additional supply than a reduction in agricultural demands.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-10. Projected change in water supply measures for the 2030s with strategies in place, expressed as percent change**

For the Upper Klamath Lake Supply measure, adaptation strategy concepts either result in no change or result in small increases in this value, thereby adding to increases in the measure for those climate change scenarios where there are increases (generally wetter scenarios), or decreasing the reduction for other scenarios (generally drier scenarios). Similarly, reduction of agricultural demands and additional inflow to Upper Klamath Lake do not have substantial impacts on mean April through September Klamath Project water supply. However, an additional 30 KAF provides greater additional supply than a reduction in agricultural demands, as indicated by greater increases in supply for the wetter scenarios and small decreases for the drier scenarios, compared with the historical simulation.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-11. Projected change in water supply measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.3 Analysis of Impacts – Hydroelectric Power

As discussed in Chapter 5, hydroelectric power measures considered in this study include mean number of spill days per year and mean annual spill volume at the major mainstem Klamath River power facilities (J.C. Boyle, COPCO 1, and Iron Gate), as well as mean annual hydropower generation summed over the four mainstem dams (those listed above plus COPCO 2). For the historical simulation period, mean annual days with spill at the three facilities are on the order of one third of days in a year for J.C. Boyle, about 12 percent of days per year for COPCO 1, and about 45 percent of days for Iron Gate. The number of spill days and the mean annual spill volumes for J.C. Boyle and COPCO 1 are projected to increase for most scenarios for both future time horizons under the baseline (climate change with no strategies in place). At Iron Gate the projected spill volume generally increases, although by a lower percentage than at J.C. Boyle

and COPCO 1, and the projected mean number of spill days per year shows a small decrease.

Projected changes in hydropower measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-12 and for the 2070s in Figure 6-13. The adaptation strategy concepts considered generally provide additional water to the mainstem Klamath River, thereby contributing to greater projected increases in mean number of spill days per year, mean annual spill volume, and mean annual hydropower production, more so for the 2070s than for the 2030s future time periods. Again, the addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes than does the decrease in agricultural demands. Projected changes in hydropower production are generally quite small compared with historical simulations, primarily because production under the historical simulation is on the order of 27,000 MW. In other words, hydropower production as a percentage does not change substantially due to the magnitude of hydropower production. Table 6-3 summarizes projected changes in mean annual hydropower production under the CT scenario for both future time periods. Implementation of the Add 30KAF strategy concept results in a 714 or 352 MW reduction in mean annual production for the 2030s, compared to 1,146 or 749 MW for the baseline (depending on consideration of CMIP3- or CMIP5-based projections). For the 2070s, the projected reduction is 468 or 1,209 MW, compared to 818 or 1,593 MW for the baseline.

## Projected Hydropower Production

The addition of 30 KAF of inflow to Upper Klamath Lake has a greater influence on projected changes in hydropower production than does the decrease in agricultural demands. Hydropower production as a percentage does not change substantially due to the magnitude of hydropower production (27,000 MW, according to historical simulations).

**Table 6-3. Summary of projected change in mean annual hydropower production for the Central Tendency scenario in units of MW**

| Central Tendency Scenario | CMIP | Baseline (MW) | Reduce ET 30% (MW) | Reduce ET 50% (MW) | Add 30KAF (MW) |
|---|---|---|---|---|---|
| Historical | | 26,741 | | | |
| 2030 | CMIP3 | -1,146 | -1,026 | -959 | -714 |
| | CMIP5 | -749 | -637 | -569 | -352 |
| 2070 | CMIP3 | -818 | -672 | -585 | -468 |
| | CMIP5 | -1,593 | -1,410 | -1,290 | -1,209 |

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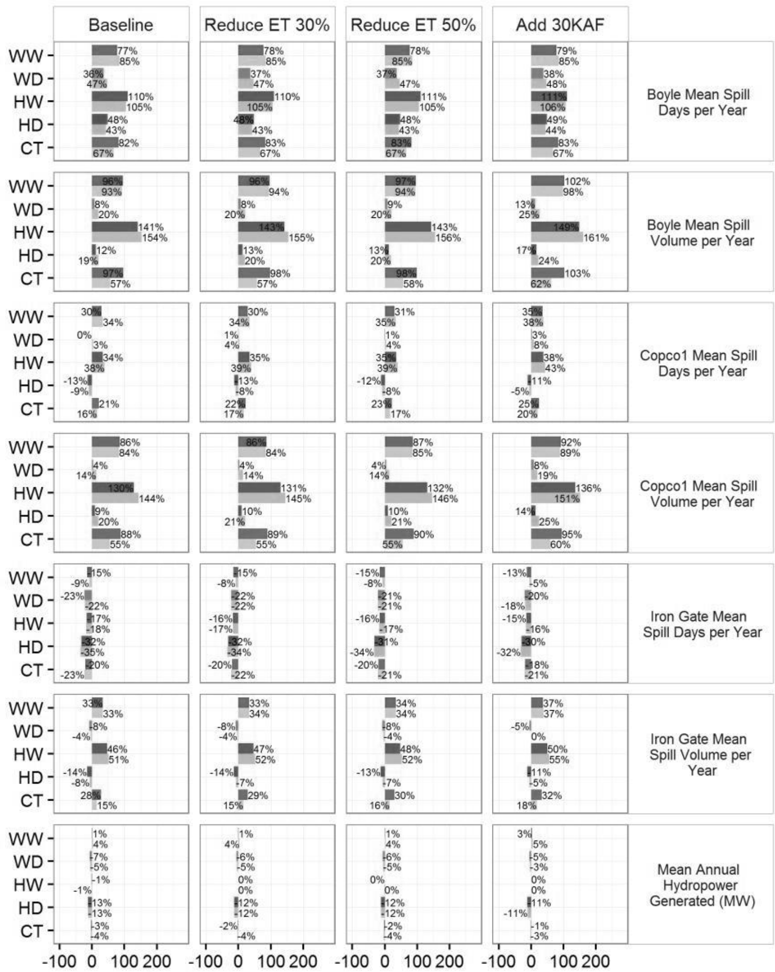
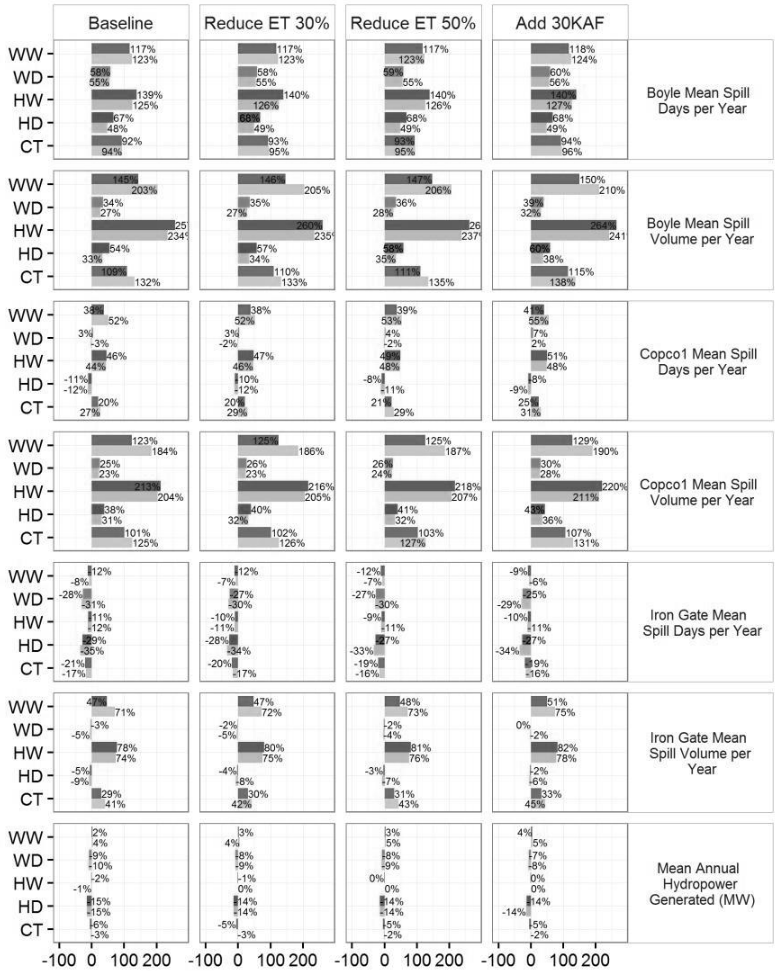



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-12. Projected change in hydroelectric power measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-13. Projected change in hydroelectric power measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.4 Analysis of Impacts – Recreation

Recreation impacts are measured based on mean annual river boating days and mean annual fishing days in various reaches of the Klamath River. As discussed in Chapter 5, recommended flow ranges were summarized in the Environmental Impact Statement/Report for dam removal (Interior and CDFG, 2012). For the

historical simulations, mean annual number of fishing days are generally greater than mean annual number of river boating days. Projected changes in fishing measures under baseline and strategy scenarios are summarized for the 2030s in Figure 6-14 and for the 2070s in Figure 6-15, while projected changes in boating measures are summarized similarly in Figure 6-16 and Figure 6-17. For fishing under the baseline scenario (climate change with no strategies in place), the drier scenarios (WD and HD) generally indicate increases in the number of fishing days, while the wetter scenarios indicate decreases in the number of fishing days for both future time horizons. These results show that recommended flow ranges for fishing do not favor high flows. Because the adaptation strategy concepts generally result in greater mainstem river flows, their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The projected changes are small on a percentage basis (on the order of 1 to 2 percent). Implementation of the strategies does not counter the effects of climate change on fishing days.

## Recreation

Adaptation strategy concepts generally result in greater mainstem river flows and their impact on fishing recreation measures is a reduction in the mean annual number of fishing recreation days, in general. The implementation of adaptation strategy results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario.

For boating recreation, the magnitude and direction of projected change in number of river boating days depends on the reach and scenario. The implementation of adaptation strategy concepts (both agricultural demand reduction and additional inflow to Upper Klamath Lake) results in smaller reductions in boating days and greater increases in the number of boating days, depending on the scenario. The strategies do not have a noticeable impact on boating recreation measures downstream of Iron Gate Dam. Upstream of Iron Gate, the strategies cause changes in the boating recreation measures by up to 2 percent for the 2030s and up to 4 percent for the 2070s, and more so for the Add 30KAF strategy scenario than for the agricultural demand reduction scenarios.

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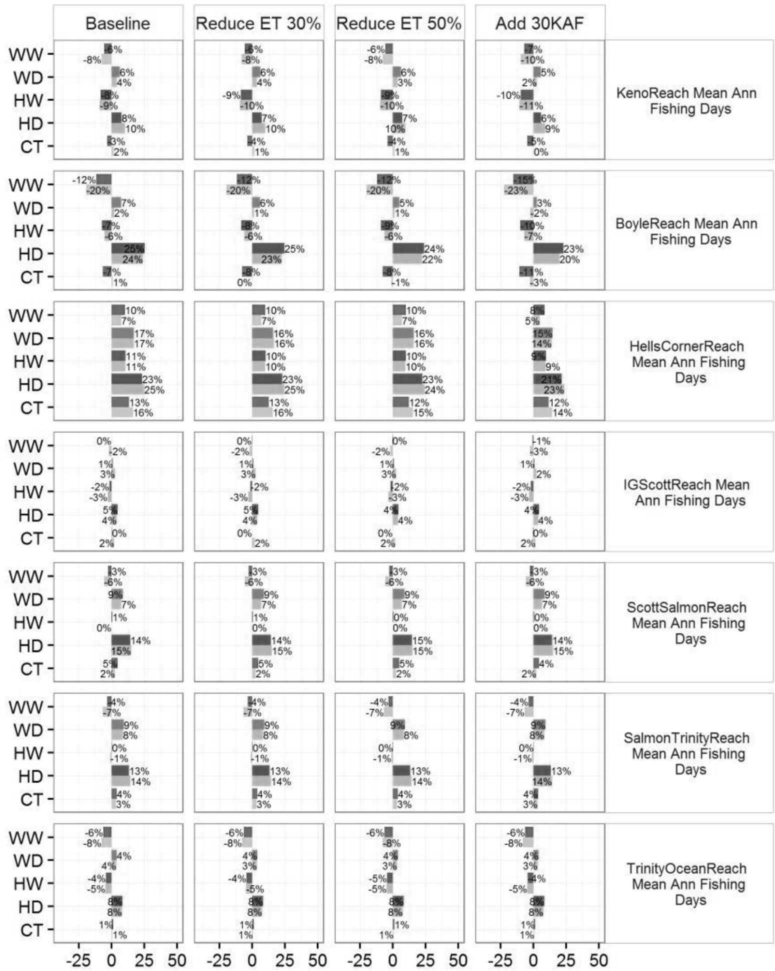


Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-14. Projected change in fishing recreation measures for the 2030s with strategies in place, expressed as percent change**

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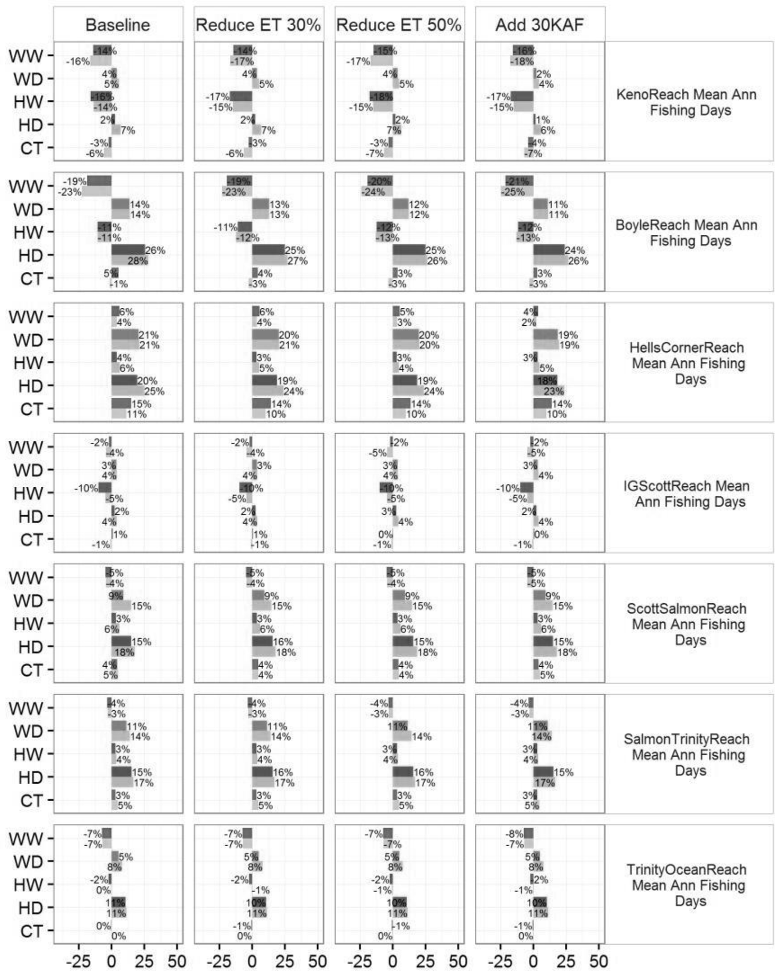
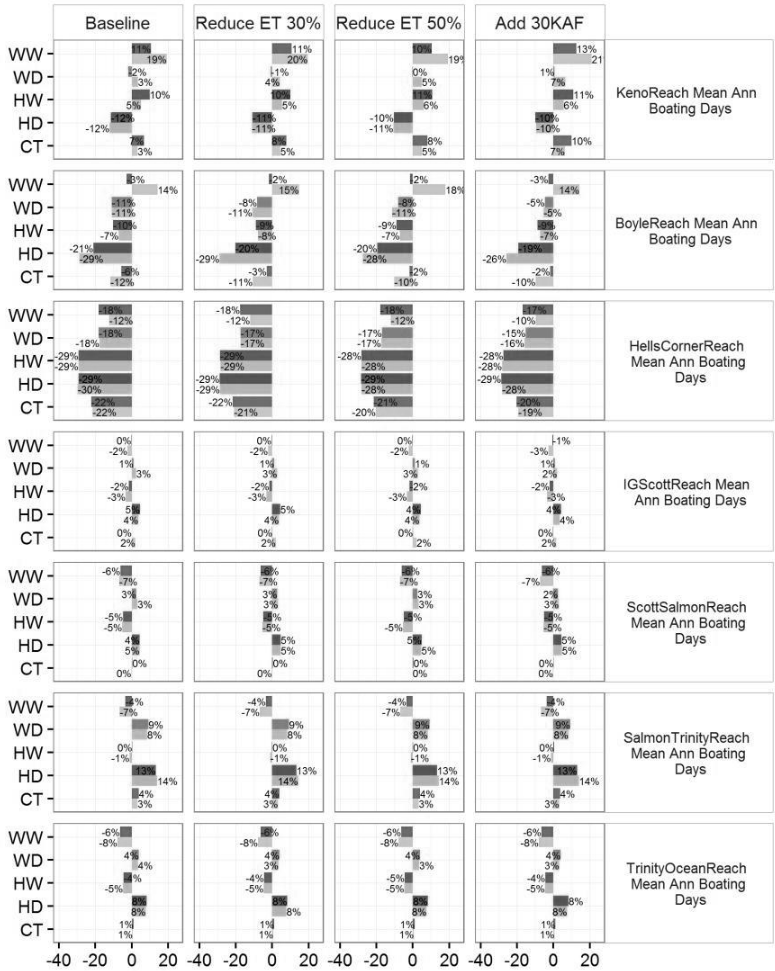


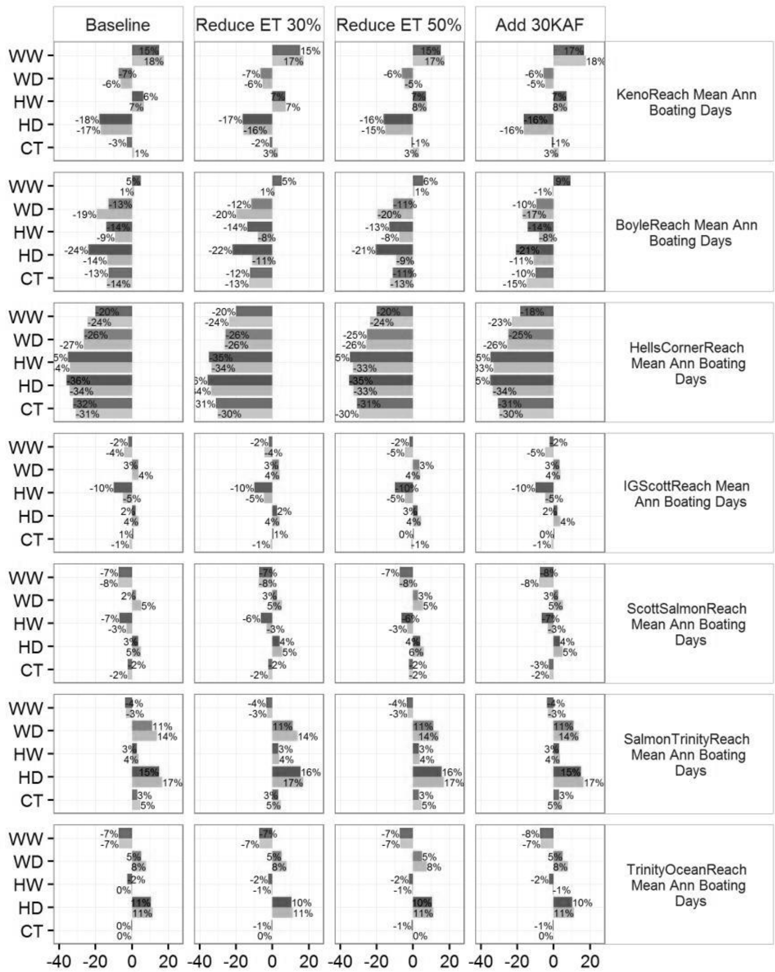

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-15. Projected change in fishing recreation measures for the 2070s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-16. Projected change in river boating recreation measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-17. Projected change in river boating recreation measures for the 2070s with strategies in place, expressed as percent change**

### 6.4.5 Analysis of Impacts – Ecological Resources

As discussed in Chapter 5, ecological resources measures considered in this study are related to needs for fish and wildlife habitat, including flow targets for SONCC ESU salmon and water supply to Lower Klamath National Wildlife Refuge (LKNWR). According to model simulations under historical hydrology, recommended flow targets that were developed specifically for the Shasta River

Basin were met 57 percent of days for the Shasta River and 71 percent of days for the Scott River (which has higher mean annual flow than the Shasta River).

Projected change in water supply measures under Baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-18 and for the 2070s in Figure 6-19. Projected changes under the baseline in the mean number of days that dry year flow targets are met in the Scott and Shasta Rivers indicate increases on a percentage basis for the wetter scenarios (WW and HW) and decreases in the drier scenarios (WD and WD), with greater change projected for the 2070s time horizon compared with the 2030s. The baseline CT scenario indicates modest decreases in the frequency of meeting recommended flow targets. The Add 30KAF strategy does not impact flows in the Scott and Shasta Rivers, so the percent change under this strategy is identical to that of the baseline scenario. A reduction in agricultural demand in these basins appears to improve the ability to meet dry year fish targets for some scenarios, but not all.

## Ecological Resources Impacts

The addition of 30 KAF of inflow to Upper Klamath Lake does not impact flows in the Scott and Shasta Rivers. Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. The additional Upper Klamath Lake inflow scenario also results in greater supply to the refuge, although to a lesser degree.

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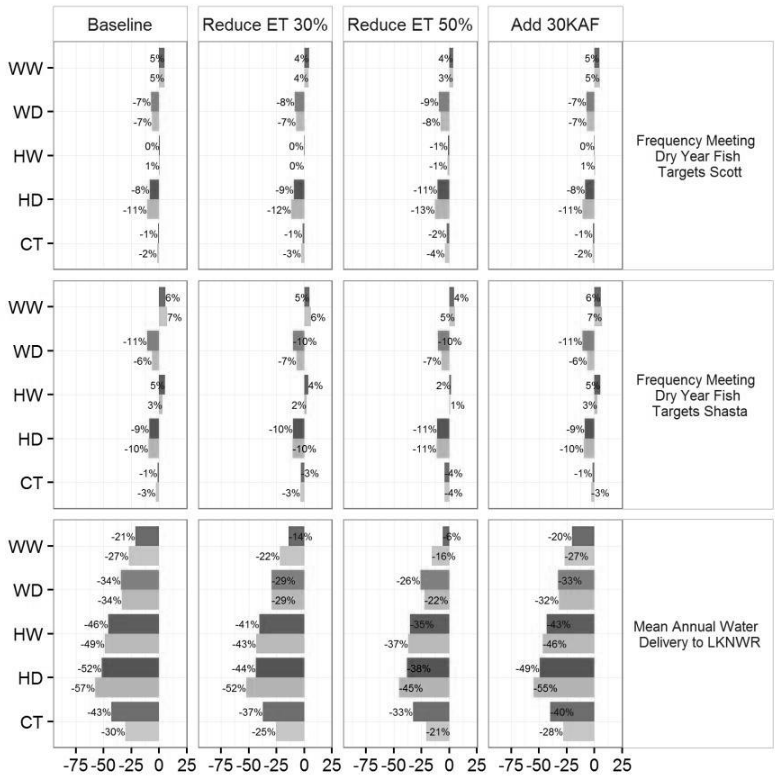
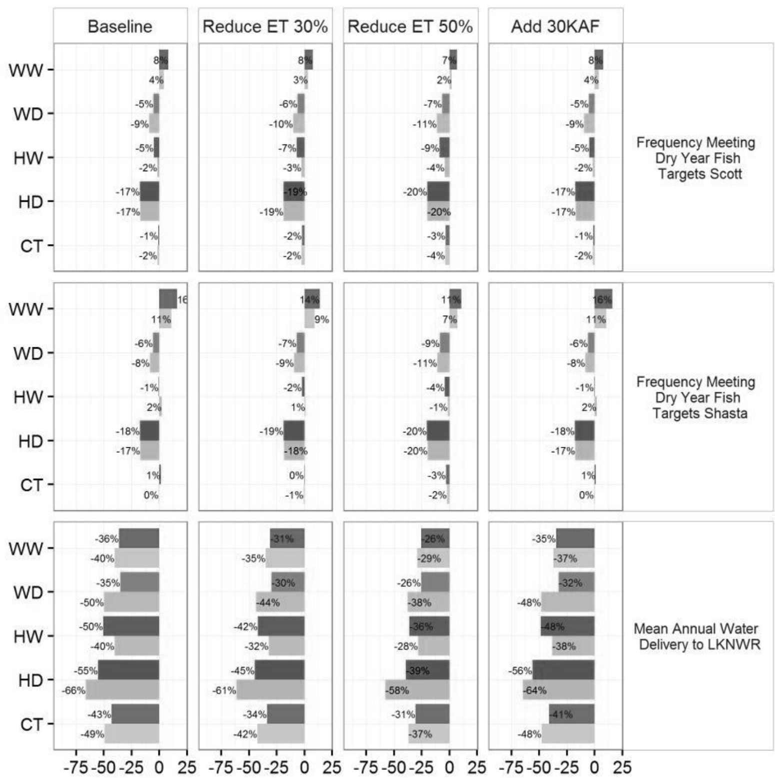



Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-18. Projected change in ecological resources measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-19. Projected change in ecological resources measures for the 2070s with strategies in place, expressed as percent change**

Reducing agricultural demands by 30 or 50 percent has a substantial impact on the availability of water for the LKNWR. For the 2030s, the projected reduction in water supply to LKNWR under the CT climate change scenario goes from a reduction of 30 or 43 percent (depending on the use of CMIP3 or CMIP5 scenarios) to a reduction of 21 or 33 percent if agricultural demands are cut in half. The Add 30KAF scenario also results in greater supply to the refuge, although to a lesser degree. For the 2070s, a 50 percent reduction in agricultural demands results in a change in the measure from 43 or 49 percent (under the baseline scenario) to 41 or 48 percent.

It may be noted that model results indicate a decrease in deliveries to LKNWR under all adaptation strategy concepts, albeit to a lesser extent than the baseline

scenario (climate change only). These results may in part be due to the fact that under the 2013 BiOp management criteria, water is supplied to other environmental needs and agricultural needs ahead of the LKNWR. Since Klamath Project supply is not projected to change substantially as a result of adaptation strategies, projected additional releases from Upper Klamath Lake may provide a greater benefit to the refuge.

### 6.4.6 Analysis of Impacts – Water Quality

As discussed in Chapter 5, water quality measures considered in this study are related to Klamath River temperature. The SONCC ESU salmon recovery plan (NMFS, 2012) provides a classification of river conditions based in part on the maximum weekly average temperature (MWAT). River temperatures were simulated using the RBM10 water temperature model developed by Perry et al. (2010). According to model simulations under historical hydrology, the river temperatures (as defined by the MWAT) for all simulated years were classified as “poor” under the salmon recovery plan. The “poor” classification threshold is 63.68 degrees F, or 17.6 degrees C. The measure considered by the basin study is the mean annual MWAT.

> **Water Quality Impacts**
>
> Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on water quality measures. Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow.

Projected changes in water quality measures under baseline and adaptation strategy concept scenarios are summarized for the 2030s in Figure 6-20 and Figure 6-21 and for the 2070s in Figure 6-22 and Figure 6-23. It should be noted that additional adaptation strategy concepts were considered that affect river temperature. One additional strategy (labeled “Reduce Scott Shasta 4degC”) focuses on reducing river temperature in the Scott and Shasta rivers by 4 degrees C (about 7 degrees F), in accordance with an existing emergency water management plan in the Shasta River basin, where groundwater may be pumped and supplied to the river in place of warmer surface water releases from reservoirs.

Other additional strategies fall under the adaptation strategy concept of evaluating the sensitivity of river temperature to changes in tributary river temperature or streamflow. These strategies include adding 10 or 20 percent of flow to the following rivers represented in the RBM10 model: Link River, Shasta River, Scott River, Salmon River, and Trinity River. These strategies are labeled as “Add Flow 10%” and “Add Flow 20%”, respectively. They also include reducing input river temperatures in different locations represented in the RBM10 model. These strategies are labeled “Reduce Tribs 4degC” and “Reduce Dam outflow 4degC.” “Reduce Tribs 4degC” includes reduction in temperature for all

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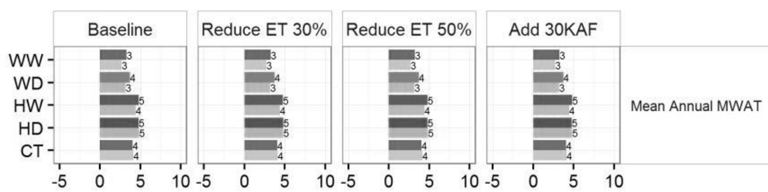
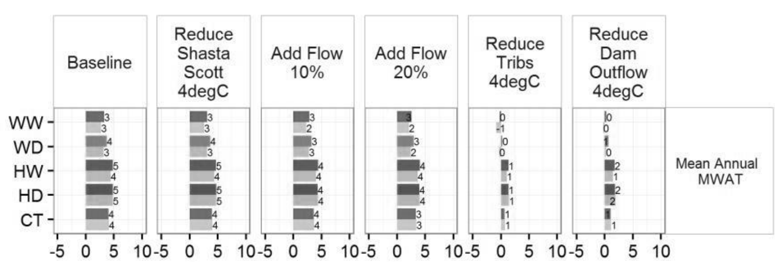
tributaries represented in the RBM10 model. “Reduce Dam Outflow 4degC” includes reducing outflow temperatures by 4 degrees C from the following locations where operations could possibly reduce water temperature: Link River, Shasta River, Scott River, and Trinity River.

Adaptation strategy concepts to reduce agricultural demand or contribute 30 KAF of additional mean annual inflow to Upper Klamath Lake have minimal impact on either water quality measure. The 2030s time period (summarized by Figure 6-20) shows no change, while the 2070s time period (summarized by Figure 6-22) shows no change based on reduction of agricultural demand by 30 percent and minimal change for the other two strategies. Figures 6-21 and 6-23 illustrate that Klamath River temperature is much more sensitive to changes in tributary temperature than to changes in streamflow. Increasing tributary flows by 20 percent has a minimal impact on Klamath River temperatures, while reducing river temperature at specific locations (where possible) results in countering climate change effects substantially, although less so by the 2070s.



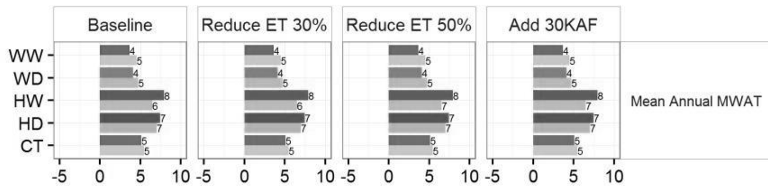

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-20. Projected change in water quality measures for the 2030s with strategies in place, expressed as degrees C**



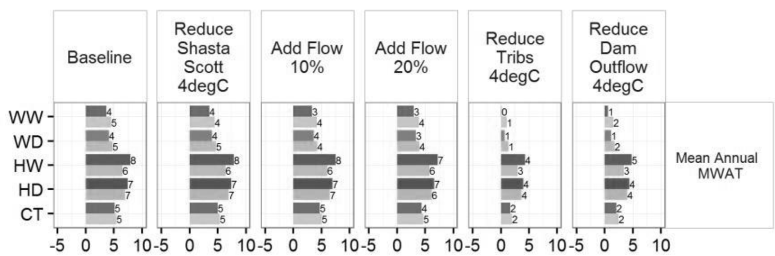

Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-21. Projected change in water quality measures for the 2030s with additional strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-22. Projected change in water quality measures for the 2070s with strategies in place, expressed as degrees C**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-23. Projected change in water quality measures for the 2070s with additional strategies in place, expressed as percent change**

### 6.4.7 Analysis of Impacts – Flood Control

As discussed in Chapter 5, flood control measures include (1) the frequency (mean number of days per year) of flood control releases from Upper Klamath Lake, (2) the mean annual flood control release volume (based on water year) from Upper Klamath Lake, and (3) the date of seasonal peak flow at three locations (J.C. Boyle Reservoir, COPCO 1 Reservoir, and Iron Gate Reservoir). Measures are computed using results from the Klamath Basin RiverWare model. Again, flood control release from Upper Klamath Lake is defined in the 2012 Proposed Action for Klamath Project Operations (Reclamation, 2012d), which is quantified as the release beyond that made to meet Klamath Project deliveries and to meet instream flow needs. Projected change in Upper Klamath Lake flood control measures under baseline and adaptation strategy concept scenarios are summarized in Figure 6-24 (2030s) and Figure 6-25 (2070s). Table 6-4 quantifies the difference between projected flood control release volume in units of KAF and the historical baseline, which addresses the question of how much additional surface water may be available for future storage under the "Additional Surface Water Storage Capacity" strategy concept.

The frequency of Upper Klamath Lake flood control release under the historical simulation is about 44 percent of days, while the corresponding mean annual flood control release volume is approximately 224 KAF. As previously discussed, flood control releases from Upper Klamath Lake were computed as the flow release beyond that required to meet Klamath Project deliveries and environmental needs. Even under historical hydrology, 44 percent of days may seem high for the percent of days of flood control release from Upper Klamath Lake. The characterization of flood control release is consistent between the RiverWare model and the KBPM. However, greater simulated flows in the Lost River system, compared with KBPM, may result in smaller demand from Upper Klamath Lake for Klamath Project supply, and therefore greater flood control release.

## Flood Control Impacts

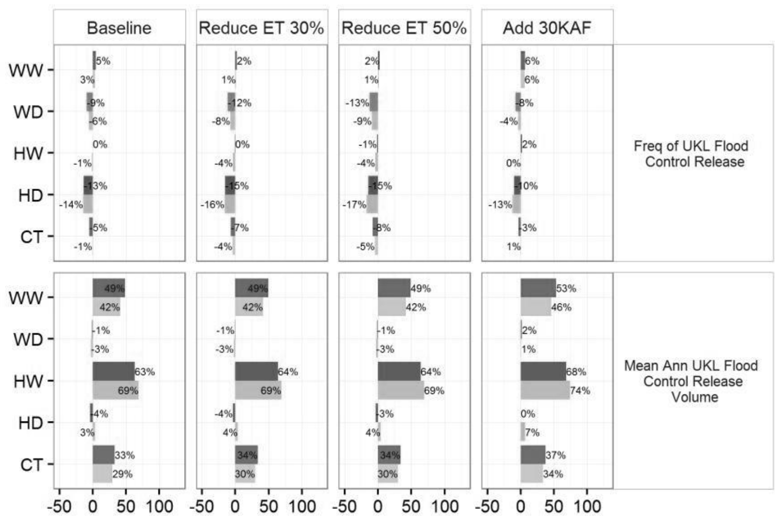
The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume. Model results indicate substantial surface water available for storage in a future climate, due to a combination of decreased snowpack and increased precipitation on an annual basis. Adaptation strategy concepts have small effects on the mean date of seasonal peak flow, indicating a difference of 2 days or less.

Projected changes indicate minimal change for the wetter scenarios (WW and HW) and a decrease for the drier scenarios (WD and HD), with the CT scenario indicating a modest decrease. At the same time, for all scenarios there is a projected increase in the mean annual flood control volume, suggesting that more water is being released in the future even though the occurrence of release may be decreasing.

Under adaptation strategy concepts in which there is a reduction in agricultural demands, additional water causes greater increases in flood control release for the wetter scenarios, and smaller decreases for the drier scenarios. The addition of 30 KAF of Upper Klamath Lake inflow has a greater impact than agricultural demand reduction on both the frequency of flood control release and the mean annual flood control volume.

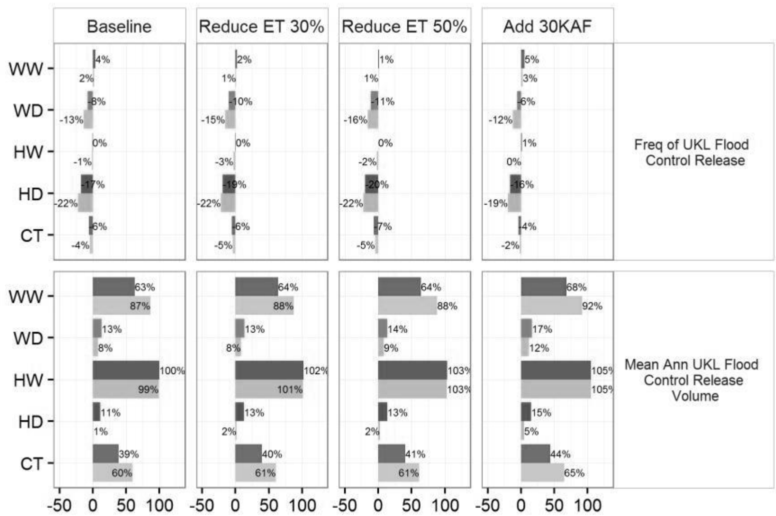
Projected changes in the date of seasonal peak flow are less substantial at J.C. Boyle Reservoir than at COPCO 1 and Iron Gate dams (refer to Table 6-5 through Table 6-7). The baseline scenario dates of seasonal peak flow are April 9 at J.C. Boyle, April 17 at COPCO 1, and April 15 at Iron Gate. Projected baseline scenario climate change effects at J.C. Boyle range from 1 to 4 days later for the 2030s to 4 days earlier to 3 days later for the 2070s, depending on the climate scenario. For COPCO 1 and Iron Gate, projected changes range from 1 day later to 9 days earlier for the 2030s and about 2 days to 2 weeks earlier for the 2070s.

Considering the adaptation strategy concepts and their effect on mean date of seasonal peak flow, both reduction of agricultural demand and addition of 30 KAF of inflow to Upper Klamath Lake have small effects, generally resulting in peak flow dates that are different by 2 days or less from the baseline. This is true at all three dam locations evaluated.




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-24. Projected change in flood control measures for the 2030s with strategies in place, expressed as percent change**




Note: darker bars represent CMIP5-based scenarios, while lighter bars represent CMIP3-based scenarios.

**Figure 6-25. Projected change in flood control measures for the 2070s with strategies in place, expressed as percent change**

Because the mean annual Upper Klamath Lake flood control release volume is a system performance measure and is also the variable used to quantify the adaptation strategy concept pertaining to additional storage volume, we summarize the projected flood control release volume for all climate change scenarios at both future time horizons. According to model simulations and the means of quantifying flood control release (i.e., that release volume beyond Klamath Project deliveries and environmental flow releases), there may be substantial additional surface water available for storage under future climate conditions. This volume may be due to projected increases in precipitation and/or the reduction in snowpack storage as temperatures are projected to warm.

**Table 6-4. Projected change in mean annual Upper Klamath Lake flood control release volume, computed as difference (in units of KAF) between scenario and historical baseline**

| Scenario | Period | BCSD Projection | Baseline (KAF) | Reduce ET 30% (KAF) | Reduce ET 50% (KAF) | Add 30KAF (KAF) |
|---|---|---|---|---|---|---|
| Historical | Historical | - | 224 | | | |
| Warm Dry | 2030 | CMIP-3 | -6 | -5 | -5 | 2 |
| Warm Dry | 2030 | CMIP-5 | -3 | -2 | -2 | 5 |
| Warm Wet | 2030 | CMIP-3 | 94 | 94 | 94 | 103 |
| Warm Wet | 2030 | CMIP-5 | 110 | 111 | 111 | 120 |
| Hot Dry | 2030 | CMIP-3 | 8 | 9 | 9 | 16 |
| Hot Dry | 2030 | CMIP-5 | -9 | -8 | -7 | 1 |
| Hot Wet | 2030 | CMIP-3 | 155 | 156 | 156 | 167 |
| Hot Wet | 2030 | CMIP-5 | 142 | 144 | 145 | 153 |
| Central Tendency | 2030 | CMIP-3 | 67 | 67 | 68 | 76 |
| Central Tendency | 2030 | CMIP-5 | 75 | 76 | 77 | 84 |
| Warm Dry | 2070 | CMIP-3 | 19 | 19 | 20 | 27 |
| Warm Dry | 2070 | CMIP-5 | 30 | 31 | 31 | 38 |
| Warm Wet | 2070 | CMIP-3 | 195 | 197 | 198 | 207 |
| Warm Wet | 2070 | CMIP-5 | 143 | 144 | 144 | 153 |
| Hot Dry | 2070 | CMIP-3 | 2 | 5 | 6 | 12 |
| Hot Dry | 2070 | CMIP-5 | 25 | 29 | 31 | 35 |
| Hot Wet | 2070 | CMIP-3 | 224 | 228 | 231 | 236 |
| Hot Wet | 2070 | CMIP-5 | 224 | 230 | 232 | 236 |
| Central Tendency | 2070 | CMIP-3 | 135 | 137 | 138 | 147 |
| Central Tendency | 2070 | CMIP-5 | 87 | 89 | 92 | 99 |

**Table 6-5. Projected change in date of seasonal peak flow at J.C. Boyle Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle | Mean Date of Seasonal Peak Flow at J.C. Boyle |
| Historical | Historical | - | April 9 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 4 | 4 | 4 | 4 |
| Warm Dry | 2030 | CMIP-5 | 4 | 4 | 4 | 3 |
| Warm Wet | 2030 | CMIP-3 | 2 | 2 | 2 | 2 |
| Warm Wet | 2030 | CMIP-5 | 2 | 2 | 2 | 2 |
| Hot Dry | 2030 | CMIP-3 | 4 | 4 | 4 | 3 |
| Hot Dry | 2030 | CMIP-5 | 4 | 4 | 4 | 3 |
| Hot Wet | 2030 | CMIP-3 | 1 | 1 | 1 | 1 |
| Hot Wet | 2030 | CMIP-5 | 2 | 2 | 2 | 2 |
| Central Tendency | 2030 | CMIP-3 | 3 | 3 | 3 | 3 |
| Central Tendency | 2030 | CMIP-5 | 2 | 2 | 2 | 1 |
| Warm Dry | 2070 | CMIP-3 | 2 | 4 | 3 | 2 |
| Warm Dry | 2070 | CMIP-5 | 3 | 3 | 3 | 3 |
| Warm Wet | 2070 | CMIP-3 | 2 | 2 | 2 | 1 |
| Warm Wet | 2070 | CMIP-5 | 2 | 2 | 2 | 2 |
| Hot Dry | 2070 | CMIP-3 | 3 | 4 | 3 | 2 |
| Hot Dry | 2070 | CMIP-5 | 1 | 2 | 2 | 1 |
| Hot Wet | 2070 | CMIP-3 | -2 | 1 | -2 | -3 |
| Hot Wet | 2070 | CMIP-5 | -4 | -3 | -3 | -4 |
| Central Tendency | 2070 | CMIP-3 | 0 | 3 | 0 | 0 |
| Central Tendency | 2070 | CMIP-5 | 2 | 2 | 2 | 2 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

**Table 6-6. Projected change in date of seasonal peak flow at COPCO 1 Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 | Mean date of seasonal peak flow at COPCO 1 |
| Historical | Historical | - | April 17 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 1 | 1 | 1 | 1 |
| Warm Dry | 2030 | CMIP-5 | 0 | 0 | 0 | 0 |
| Warm Wet | 2030 | CMIP-3 | -4 | -4 | -4 | -5 |
| Warm Wet | 2030 | CMIP-5 | -5 | -5 | -5 | -5 |
| Hot Dry | 2030 | CMIP-3 | -4 | -3 | -3 | -4 |
| Hot Dry | 2030 | CMIP-5 | -3 | -3 | -3 | -3 |
| Hot Wet | 2030 | CMIP-3 | -9 | -9 | -9 | -9 |
| Hot Wet | 2030 | CMIP-5 | -8 | -8 | -8 | -8 |
| Central Tendency | 2030 | CMIP-3 | -3 | -4 | -3 | -4 |
| Central Tendency | 2030 | CMIP-5 | -6 | -6 | -6 | -6 |
| Warm Dry | 2070 | CMIP-3 | -5 | -5 | -4 | -5 |
| Warm Dry | 2070 | CMIP-5 | -2 | -2 | -2 | -2 |
| Warm Wet | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Warm Wet | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-3 | -8 | -7 | -7 | -8 |
| Hot Dry | 2070 | CMIP-5 | -8 | -8 | -8 | -8 |
| Hot Wet | 2070 | CMIP-3 | -15 | -15 | -14 | -15 |
| Hot Wet | 2070 | CMIP-5 | -17 | -17 | -17 | -17 |
| Central Tendency | 2070 | CMIP-3 | -10 | -10 | -10 | -11 |
| Central Tendency | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

**Table 6-7. Projected change in date of seasonal peak flow at Iron Gate Reservoir**

| Scenario | Period | BCSD | Baseline | Reduce ET 30% | Reduce ET 50% | Add 30KAF |
|---|---|---|---|---|---|---|
| | | Projection | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate | Mean date of seasonal peak flow at Iron Gate |
| Historical | Historical | - | April 15 | - | - | - |
| Warm Dry | 2030 | CMIP-3 | 1 | 1 | 1 | 0 |
| Warm Dry | 2030 | CMIP-5 | 0 | 0 | 0 | 0 |
| Warm Wet | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Warm Wet | 2030 | CMIP-5 | -5 | -5 | -5 | -5 |
| Hot Dry | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Hot Dry | 2030 | CMIP-5 | -3 | -3 | -3 | -3 |
| Hot Wet | 2030 | CMIP-3 | -9 | -9 | -9 | -9 |
| Hot Wet | 2030 | CMIP-5 | -8 | -8 | -8 | -8 |
| Central Tendency | 2030 | CMIP-3 | -4 | -4 | -4 | -4 |
| Central Tendency | 2030 | CMIP-5 | -6 | -5 | -5 | -6 |
| Warm Dry | 2070 | CMIP-3 | -5 | -5 | -5 | -5 |
| Warm Dry | 2070 | CMIP-5 | -2 | -2 | -2 | -2 |
| Warm Wet | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Warm Wet | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-3 | -7 | -7 | -7 | -7 |
| Hot Dry | 2070 | CMIP-5 | -8 | -8 | -7 | -8 |
| Hot Wet | 2070 | CMIP-3 | -14 | -14 | -13 | -14 |
| Hot Wet | 2070 | CMIP-5 | -16 | -16 | -15 | -16 |
| Central Tendency | 2070 | CMIP-3 | -10 | -10 | -10 | -10 |
| Central Tendency | 2070 | CMIP-5 | -7 | -7 | -7 | -7 |

Note: Scenarios with a perceptible change in the mean date of seasonal peak flow are highlighted.

## 6.5 Key Findings and Next Steps

Klamath River water users and stakeholders have long have long called for a comprehensive and integrated approach to water management to balance the needs of all water users. The Basin Study Report evaluates current and projected future water supply and demand assessments to refine existing projections of climate change's effect on the Klamath River Basin, and provide stakeholders in the region the opportunity to identify and evaluate potential adaptation strategies which may reduce identified imbalances. These adaptation strategies provide water users, stakeholders, and Reclamation with understanding of the degree to which actions including those to increase supply, decrease demand, and modify operations could reduce supply and demand imbalances that are projected to increase as a result of climate change. The Basin Study builds on earlier work and is the next significant step in developing a comprehensive knowledge base

and suite of tools and options that could address the risks posed by Klamath River Basin water supply-demand imbalances.

Results from model simulations with and without adaptation strategy concepts in place indicate that the strategies have modest abilities to reduce climate change impacts. Considered strategies include agricultural water conservation, additional inflow to Upper Klamath Lake, quantification of potential surface water storage, and evaluation of changes in flow and tributary temperature on Klamath River temperature at Klamath, California.

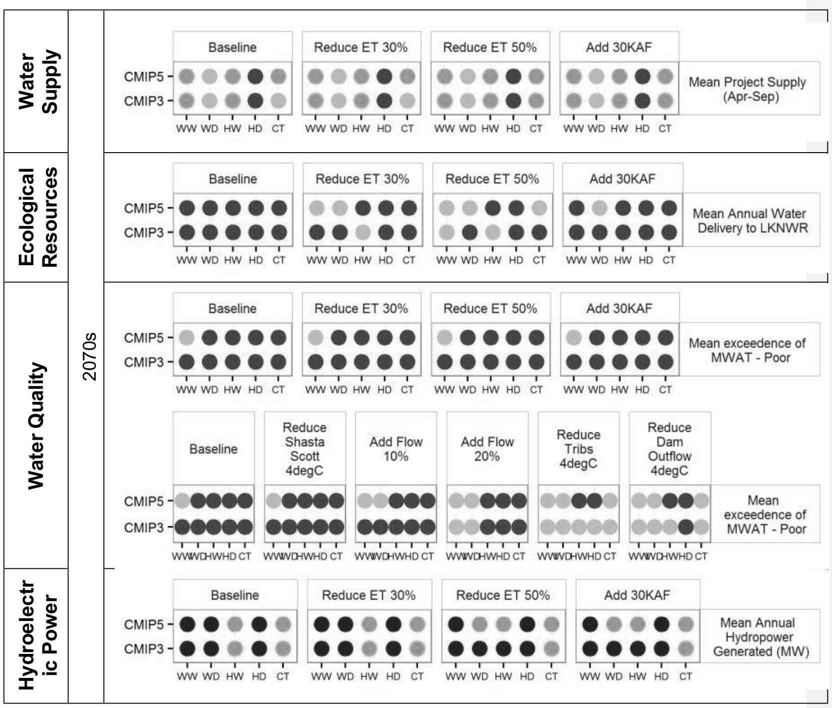
The addition of inflow to Upper Klamath Lake appears to result in the greatest change in computed basin-wide response variables and selected performance measures. With respect to sensitivities of river temperature, the reduction in tributary temperature has a greater impact than does change in flow. Also, according to model simulations, substantial surface water may be available for storage in the future due to reduction in snowpack storage and projected changes in precipitation timing and volume. The location for quantification of additional storage is at Upper Klamath Lake; however, this study does not explore locations for future surface water storage.

Figure 6-26 summarizes projected changes in four select system performance measures for the 2070s future time period, compared with the historical simulation. Projected changes are computed using CMIP3- and CMIP5-based projections, and for each of the five climate change scenarios. The baseline scenario represents climate change only, without adaptation strategy concepts in place. The other scenarios represent changes with adaptation strategy concepts. For this figure, projected changes on a percentage basis were divided into four bins: two bins for positive change and two bins for negative change. Darker circles represent the bin with greater change. Green circles indicate an improvement in the selected measure, while red circles indicate a worsening of the measure. The results summarized in the figure allow for a high level understanding of the direction of change, and highlight which strategies provide the greatest change compared with the baseline scenario.

In Figure 6-26, with respect to mean April–September Klamath Project supply, neither reduction in agricultural demand nor additional Upper Klamath Lake inflow of 30 KAF cause a substantial change compared with the baseline scenario. For mean annual water supply to LKNWR, reduction in agricultural demands results in a meaningful improvement, compared with the baseline scenario. For mean exceedance of the “poor” water quality classification (through calculation of the MWAT), reduction in tributary water temperatures has a greater influence on resulting river temperatures than changes in streamflow. It is likely not realistic to expect a reduction in temperatures in unmanaged tributaries, but changes in managed flows (i.e., Link River, Shasta River, Scott River, Trinity River) still have a meaningful impact, compared with the baseline scenario. For mean annual hydropower generation, it is apparent that climate change, and adaptation strategy concepts, result in greater hydropower production. Reduction

of agricultural demands by 50 percent and additional Upper Klamath Lake inflow of 30 KAF result in noticeable change from the baseline, while a less substantial reduction in agricultural demands (30 percent) does not provide substantial additional benefit.

Overall, climate change adversely affects mean annual deliveries to LKNWR and river temperatures; it may adversely affect or may be favorable to mean Klamath Project Supply (April–September) depending on the climate change scenario, and is likely to be favorable to mean annual hydropower production. Adaptation strategy concepts evaluated in the Basin Study do not substantially counter the effects of climate change. However, in general the addition of 30 KAF inflow to Upper Klamath Lake appears to have a greater benefit to the system reliability than does reduction in agricultural demands, based on model simulations.




Notes: Green circles indicate an improvement in the measure for the future, while red circles indicate a worsening in the measure for the future. Darker circles indicate greater change than lighter circles.

**Figure 6-26. Summary of projected changes in select measures for the 2070s, with and without strategies in place**

### 6.5.1 Refinement of Adaptation Strategies and Next Steps

The Basin Study Report indicates that implementation of projects to improve water supply, decrease demand, and modify operations can provide some improvement in the reliability and sustainability of the Klamath River system to help meet current and future water demands. The adaptation strategies evaluated in this Basin Study would all need to be further studied to refine the understanding of these potential benefits and develop plans for their implementation. Similar to this Basin Study, the agencies and stakeholders that would need to be involved in that refinement process would need to include all those potentially affected by their implementation.

The Klamath River Basin Study relied on projected future conditions that were developed utilizing existing model frameworks and inputs. Identified adaptation strategies evaluated by the Basin Study are general (i.e., not specific proposed projects) by design and are intended to identify sensitivities of the Klamath Basin to various types of potential actions. Moving forward, a number of tasks have been identified to further enhance our understanding of climate change impacts on the Klamath River Basin.

- Refinement of ecosystem demands and vulnerabilities – Additional analysis of the relationship between changes in the climate, changes in the demands of aquatic, wetland, and riparian ecosystems that result from changes in the climate, and the ability to accommodate these demands with existing supplies would further support and refine the findings in this study. Additionally, incorporation of developing river temperature modeling for the Trinity River by the U.S. Geological Survey could enhance our understanding of climate change impacts and implemented adaptation strategies on river temperatures.

- Coupled groundwater/surface water model development – Expansion of existing groundwater models for the Scott and Shasta rivers to cover broader portions of the basin would further support the analysis completed in this Basin Study.

- Reservoir Operations Refinement – Current funding by the Bureau of Reclamation Office of Policy for a Klamath River Basin reservoir operations pilot study on Upper Klamath Lake will enhance the ability to quantify Upper Klamath Lake inflows and provide for an improved understanding of Upper Klamath Lake operations.

- Effects of future policy changes – Evolving policy conditions are anticipated in the Klamath River Basin relating to future ESA consultations and potential removal of the four mainstem Klamath River dams. Continued analysis of future policies using the Basin Study modeling framework will allow for comparisons to be made, and for greater understanding of potential climate change impacts.

## 6.6 References Cited

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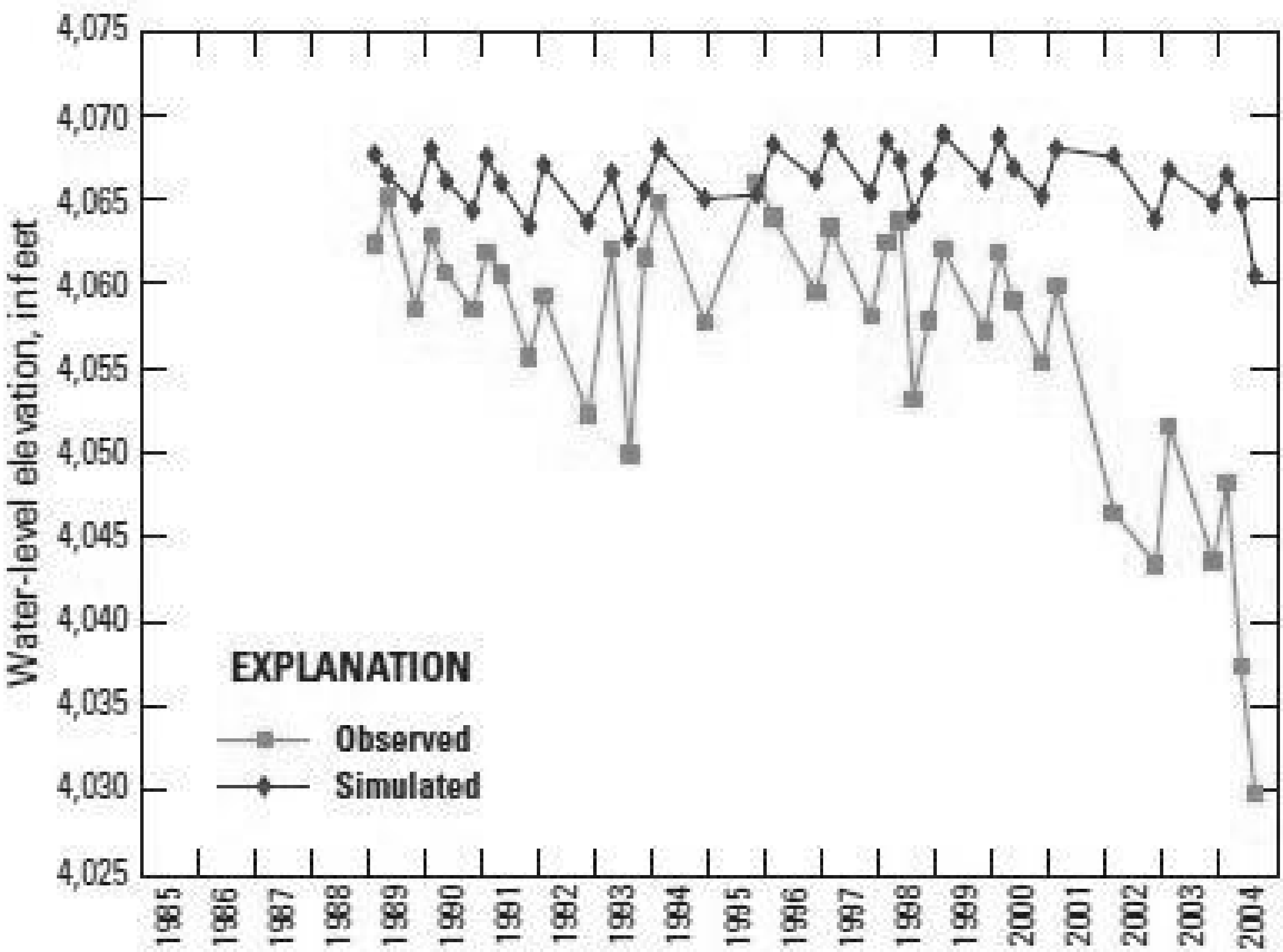


**Figure 36.** Observed and simulated water-level elevations in well 41S/9E-12AAB1 (OWRD Log ID KLAM 14914) in the Lower Klamath Lake subbasin, Oregon.

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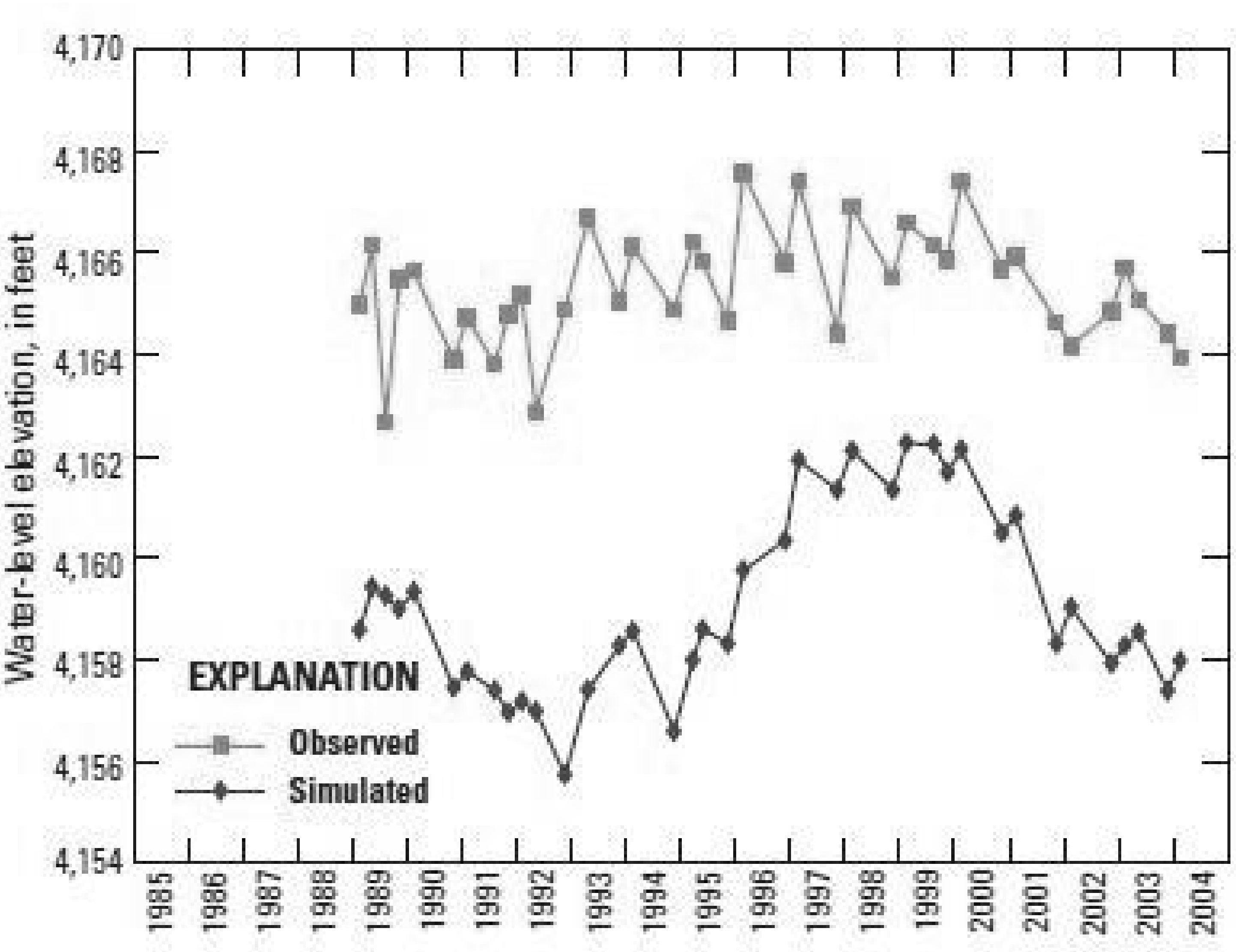


**Figure 18.** Observed and simulated water-level elevations in well 35S/7E-34CBC1 (OWRD Log ID KLAM 1362) in the Wood River subbasin, Oregon.

The information presented in this report was developed in conjunction with basin stakeholders and is intended to inform and assist stakeholders by identifying potential future scenarios for long term planning. The analyses provided in this report reflect the use of best available datasets and data development methodologies at the time of the study. In accordance with common practice, the impacts assessment methodology employed here is based on using a series of models with the outputs of one model serving as the input to the next model. Since there are uncertainties associated with each model step, and the inputs driving each model step are themselves uncertain, this can lead to a "cascade of uncertainty" (IPCC 2007, here), although there may be situations where one model's tendency to over- or under-estimate may be countered at least to some extent by another's tendency to err in the other direction. While this study has not developed an estimate of the cumulative uncertainties in the results based on this methodology, it is important to acknowledge the uncertainties inherent within projecting future planning conditions for water supply and demand. For example, projections of future climate, population, water demand, and land use contain uncertainties that vary geographically and temporally depending on the model and methodology used. Trying to identify an exact impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. Accounting for these uncertainties, Reclamation and its stakeholders used a scenario planning approach that encompasses the estimated range of future planning conditions.

Significant potential sources of uncertainties include:

- [I would include a brief list based on the Uncertainty discussions in the various chapters (as modified).
- As the first bullet, I would nominate the following: "GCMs perform better at the global rather than regional or basin levels. Moreover, based on preliminary information (~15 years' worth of data), GCM estimates of the rate of global warming may be running too high. However, the use of bias corrected models may reduce, if not eliminate, some of the systematic biases."]
- Another bullet: "The modeling effort did not account for changes in the composition of vegetation or the direct effects of $CO_2$. The latter includes potential increases in photosynthetic rates and water use efficiency in vegetation. An increase in water use efficiency might help reduce agricultural water demand, and, unless overwhelmed by an increase in production, it might increase runoff, soil moisture and groundwater recharge."

More detailed information about uncertainties related to each part of the study is available in the Klamath River Basin Study Full Report.

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Hello everyone,
The issuance of Every Kid in a Park 4th Grade Passes continues to be strong.  Attached is the latest report.

Thanks...Brooke

Brooke Linford
National Park Service
Interagency Pass Program Manager
1849 C Street, NW
Room 2345
Washington, DC 20240

Phone: 202-513-7139

# Every Kid in a Park 4th Grade Pass

**Reported in Redemption Site 9/1/2016 - 5/31/2017**

**FOR INTERNAL USE ONLY**

## Grand Total **139,217**

| | |
|---|---|
| **BLM** | **6,598** |
| California BLM Office | 1,078 |
| Red Rock Canyon National Conservation Area BLM | 1,038 |
| National Historic Trails Interpretive Center | 706 |
| Red Rock Canyon National Conservation Area - BLM | 417 |
| Idaho State Office - BLM | 362 |
| Eagle Lake BLM Field Office | 351 |
| BLM Eastern States Office | 342 |
| BLM Prineville Office | 248 |
| Pompeys Pillar Interpretive Center - BLM | 234 |
| Klamath Falls Resource Area | 207 |
| Gunnison Gorge National Conservation Area | 204 |
| Idaho BLM Office | 197 |
| Redding BLM Field Office | 192 |
| Eastern States BLM Field Office | 165 |
| Palm Springs - South Coast BLM Field Office | 144 |
| Ukiah BLM Field Office | 134 |
| Alturas BLM Field Office | 99 |
| Nevada BLM Office | 98 |
| Coos Bay BLM District Office | 69 |
| Rio Puerco BLM Field Office | 59 |
| Casper Field Office - BLM | 58 |
| BLM Medford Office | 54 |
| Arizona Strip District Office (in Utah) | 54 |
| Colorado BLM Office | 21 |
| Arizona Strip BLM Field Office (also Grand Canyon-Parashant National Monument) | 13 |
| Miles City BLM Office | 13 |
| Yaquina Head Oustanding Natural Area | 11 |
| Spokane BLM Office | 9 |
| Utah BLM Office | 4 |
| Royal Gorge BLM Field Office | 4 |
| Grand Junction BLM Field Office | 3 |
| Arizona BLM State Office | 2 |
| Las Vegas BLM Field Office | 2 |
| Wyoming BLM Office | 2 |
| Kremmling BLM Field Office | 1 |
| Richfield BLM Field Office | 1 |

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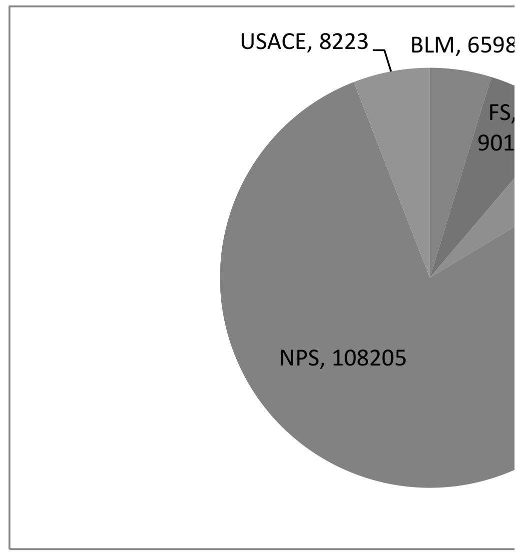
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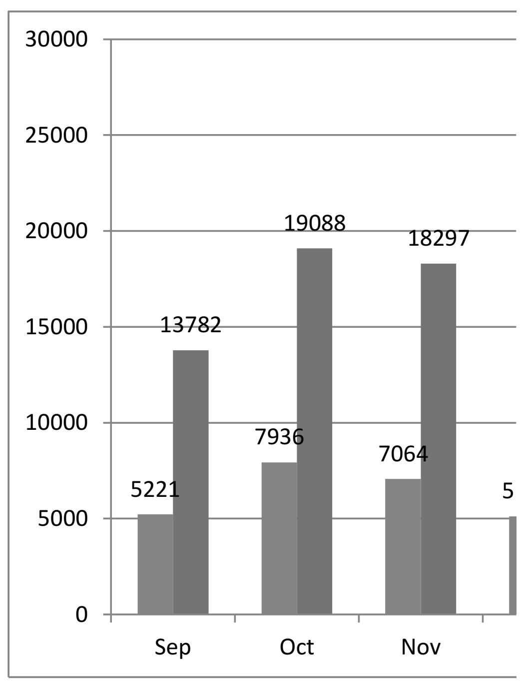
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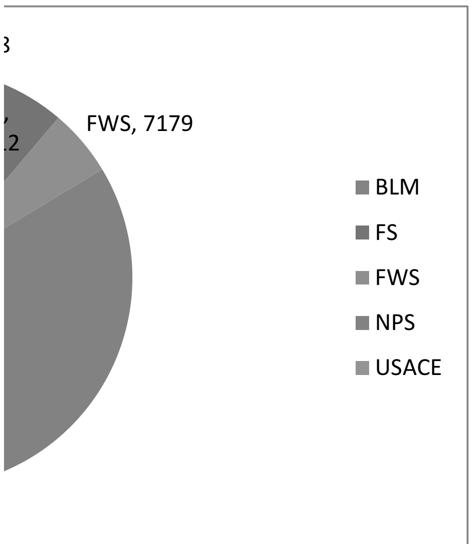


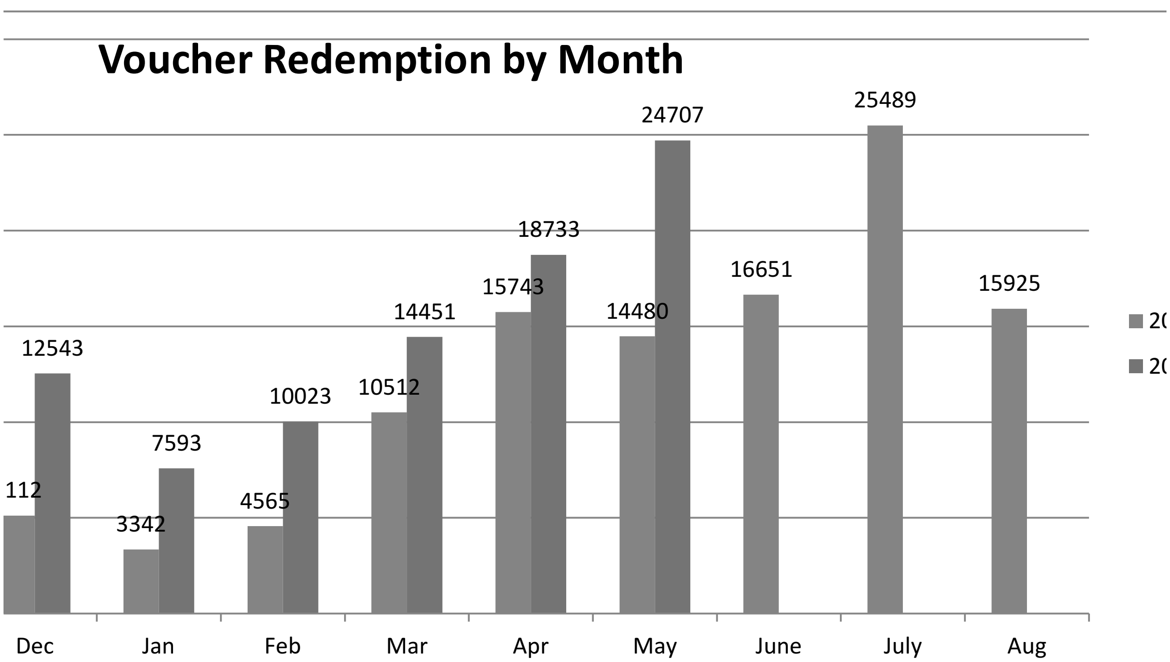

015/2016

016/2017

| | |
|---|---|
| Rock Springs Field Office - BLM | 1 |
| Eugene District BLM Office | 1 |
| **FS** | **9,012** |
| Apache-Sitgreaves NF - Lakeside District | 734 |
| Land Between the Lakes | 686 |
| Stanislaus NF - Mi-Wok District | 500 |
| Chugach National Forest | 404 |
| Lincoln NF - Sacramento District | 397 |
| Rogue River - Siskiyou NF - Main Office | 368 |
| Lewis & Clark NF - Main Office | 361 |
| US Forest Service Region 9 | 343 |
| Umpqua NF - Main Office | 340 |
| Caribou-Targhee NF - Ashton/Island Park District | 298 |
| Cibola NF - Main Office | 292 |
| Fremont-Winema NF - Main Office | 247 |
| US Forest Service Regional Office | 238 |
| Ottawa NF - Visitor Center | 226 |
| Uinta-Wasatch-Cache NF - Pleasant Grove District | 182 |
| Umpqua NF - Diamond Lake Visitor Center | 181 |
| White Mountain NF - Main Office | 169 |
| San Bernardino NF - Mountaintop District - Big Bear Ranger Station | 149 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Paonia District | 111 |
| Ocala NF - Lake George District | 110 |
| Apache-Sitgreaves NF - Springerville District | 109 |
| Apache-Sitgreaves NF - Alpine District | 109 |
| Bighorn NF - Powder River District | 108 |
| Caribou-Targhee NF - Dubois District | 107 |
| Coconino NF - Red Rock Visitor's Center | 103 |
| Pike & San Isabel NF - South Platte District | 99 |
| Olympic NF - Main Office | 94 |
| Shawnee NF - Mississippi Bluffs District | 90 |
| Eldorado NF - Main Office | 89 |
| Tongass NF - Mendenhall Glacier Visitor's Center | 88 |
| Allegheny NF - Bradford District | 88 |
| Carson NF - Main Office | 71 |
| Coconino NF - Red Rock District | 68 |
| Malheur NF - Emigrant Creek District | 67 |
| Mt Hood NF - Hood River District | 65 |
| Okanogan-Wenatchee NF - Tonasket District | 60 |
| Clearwater NF - Main Office | 55 |
| Mt Hood NF - Zigzag District | 54 |
| Umpqua NF - North Umpqua District | 51 |
| Outdoor Recreation Information Center - Seattle Flagship REI Store | 42 |
| Colville NF - Republic District | 40 |
| Coronado NF - Main Office | 36 |

**6.5%**

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| | |
|---|---|
| Bighorn NF - Main Office | 34 |
| Uinta-Wasatch-Cache NF - American Fork Fee Station | 33 |
| Mt Baker/Snoqualmie NF - Snoqualmie District | 29 |
| Shasta-Trinity NF - Main Office | 28 |
| Black Hills NF - Mystic District | 28 |
| Gifford Pinchot NF - Mt Adams District | 27 |
| San Bernardino NF - Front Country District - Cajon Ranger Station | 26 |
| Humboldt-Toiyabe NF - Bridgeport District | 24 |
| Apache-Sitgreaves NF - Supervisor's Office | 24 |
| Tonto NF - Main Office | 23 |
| Tonto NF - Mesa District | 22 |
| Uinta-Wasatch-Cache NF - Heber-Kamas District | 22 |
| Washington & Jefferson NF - Lee District | 20 |
| Prescott NF - Bradshaw District | 20 |
| Grand Mesa, Uncompahgre, & Gunnison NF - Grand Valley District | 20 |
| Arapahoe & Roosevelt NF - Clear Creek District | 19 |
| Deschutes NF - Bend/Fort Rock District | 17 |
| Sequoia NF - Kern River District - Lake Isabella Office | 17 |
| Carson NF - El Rito Station | 17 |
| Sequoia NF - Main Office | 17 |
| San Bernardino NF - Main Office | 17 |
| Fishlake NF - Fillmore District | 17 |
| Kaibab NF - North Kaibab District | 15 |
| Humboldt-Toiyabe NF - Main Office | 15 |
| Bridger-Teton NF - Pinedale District | 14 |
| Manti-La Sal NF - Sanpete District | 14 |
| Okanogan-Wenatchee NF - Cle Elum District | 13 |
| Gifford Pinchot NF - Main Office | 13 |
| Sawtooth NF - Fairfield District | 13 |
| Tonto NF - Cave Creek District | 12 |
| Caribou-Targhee NF - Westside District | 12 |
| Mt Baker/Snoqualmie NF - Enumclaw Office | 12 |
| Santa Fe NF - Main Office | 11 |
| Apache-Sitgreaves NF - Black Mesa District | 11 |
| Idaho Panhandle NF - Coeur d'Alene River District | 10 |
| Tongass NF - Southeast Alaska Discovery Center | 10 |
| Siuslaw NF - Main Office | 9 |
| Sawtooth NF - Main Office | 9 |
| Black Hills NF - Main Office | 9 |
| Pike & San Isabel NF - Salida District | 9 |
| Coconino NF - Main Office | 9 |
| Coronado NF - Santa Catalina District | 8 |
| Olympic NF - Pacific District | 8 |
| Fishlake NF - Main Office | 8 |
| Six Rivers NF - Mad River District | 8 |

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| | |
|---|---|
| Manti-La Sal NF - Main Office | 8 |
| Kaibab NF - Williams District | 7 |
| Coconino NF - Mogollon Rim District | 6 |
| Fishlake NF - Fremont River District | 6 |
| Sawtooth NF - Minidoka District | 6 |
| Bighorn NF - Medicine Wheel/Paintrock District | 6 |
| Flathead NF - Tally Lake District | 6 |
| Arapahoe & Roosevelt NF - Canyon Lakes District | 5 |
| Cleveland NF - Trabuco District | 5 |
| San Bernardino NF - San Jacinto District | 5 |
| Arapahoe & Roosevelt NF - Boulder District | 5 |
| Nebraska National Forest - Pine Ridge District | 5 |
| Kaibab NF - Main Office | 5 |
| White River NF - Dillon District | 5 |
| Umatilla NF - Walla Walla District | 5 |
| Colville NF - Newport District | 4 |
| Willamette NF - McKenzie River District | 4 |
| Uinta-Wasatch-Cache NF - Evanston District | 4 |
| Prescott NF - Chino District | 4 |
| Caribou-Targhee NF - Palisades District | 4 |
| Mt Hood NF - Clackamas River District | 3 |
| Klamath NF - Main Office | 3 |
| Rogue River - Siskiyou NF - Wild Rivers District | 3 |
| Inyo NF - Mammoth Lakes Center | 3 |
| Payette NF - McCall District | 3 |
| Okanogan-Wenatchee NF - Main Office | 3 |
| Rogue River - Siskiyou NF - Powers District | 3 |
| Malheur NF - Main Office | 3 |
| Arapahoe & Roosevelt NF - Sulphur District | 3 |
| Humboldt-Toiyabe NF - Carson District | 3 |
| Klamath NF - Scott River & Salmon River Districts | 3 |
| Angeles NF - Main Office | 3 |
| Green Mountain NF - Middlebury Station | 3 |
| Crooked River National Grasland | 3 |
| Helena NF - Lincoln District | 2 |
| Rogue River - Siskiyou NF - Gold Beach District | 2 |
| San Juan NF - Dolores District | 2 |
| Uinta-Wasatch-Cache NF - Logan District | 2 |
| Fishlake NF - Beaver District | 2 |
| Beaverhead-Deerlodge NF - Main Office | 2 |
| Nez Perce NF - Main Office | 2 |
| Caribou-Targhee NF - Montpelier District | 2 |
| Coronado NF - Douglas District | 2 |
| Okanogan-Wenatchee NF -Wenatchee River District | 2 |
| Rogue River - Siskiyou NF - High Cascades District | 2 |

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| | |
|---|---|
| White Mountain NF - Saco District | 2 |
| Black Hills NF - Bearlodge District | 2 |
| Idaho Panhandle NF - Main Office | 2 |
| San Bernardino NF - Front Country District - San Gorgonio Ranger Station | 2 |
| Sawtooth NF - Ketchum District | 2 |
| Hoosier National Forest | 2 |
| Shasta-Trinity NF - Shasta Lake Station | 2 |
| Willamette NF - Detroit District | 2 |
| Helena NF - Helena District | 2 |
| Gallatin NF - Hebgen Lake District | 1 |
| Sawtooth NF - Stanley District | 1 |
| Ozark - St. Francis NF - Sylamore Mountain District | 1 |
| San Juan NF - Pagosa District | 1 |
| Angeles NF - San Gabriel River District | 1 |
| Six Rivers NF - Orleans District | 1 |
| Ashley NF - Duchesne District | 1 |
| Rio Grande NF - Conejos Peak District | 1 |
| Shasta-Trinity NF - Mount Shasta Station | 1 |
| Los Padres NF - Main Office | 1 |
| Mendocino NF - Upper Lake District | 1 |
| Green Mountain NF - Main Office | 1 |
| Siuslaw NF - Waldport Office | 1 |
| Okanogan-Wenatchee NF - Naches District | 1 |
| Routt NF - Parks Walden District | 1 |
| Sam Houston NF | 1 |
| Huron-Manistee NF - Cadillac/Manistee District | 1 |
| Mt Baker/Snoqualmie NF - Mt Baker District | 1 |
| Ashley NF - Flaming Gorge District | 1 |
| Black Hills NF - Hell Canyon District | 1 |
| Lincoln NF - Guadalupe District | 1 |
| Grand Mesa, Uncompahgre, & Gunnison NF | 1 |
| Grey Towers National Historic Site | 1 |
| Sierra NF - Main Office | 1 |
| Mendocino NF - Main Office | 1 |
| Tahoe NF - Main Office | 1 |
| Shasta-Trinity NF - Weaverville Station | 1 |
| Ozark - St. Francis NF - Boston Mountain District | 1 |
| San Juan Public Lands Center - FS | 1 |
| Rogue River - Siskiyou NF - Siskiyou Mountains District | 1 |
| Payette NF - New Meadows District | 1 |
| Croatan NF - Main Office | 1 |
| Routt NF - Hahans Peak/Bears Ears District | 1 |
| Idaho Panhandle NF - St. Joe District | 1 |
| Dakota Prairie Grasslands - Medora District | 1 |
| Umatilla NF - Main Office | 1 |

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| | |
|---|---|
| Nantahala NF - Highlands District | 1 |
| Umpqua NF - Cottage Grove District | 1 |
| Rio Grande NF - Divide District | 1 |
| Wallowa-Whitman NF - Main Office | 1 |
| Kaibab NF - Tusayan District | 1 |
| Gifford Pinchot NF - Cowlitz Valley District | 1 |
| Colville NF - Three Rivers District | 1 |
| **FWS** | **7,179** |
| J.N. "Ding" Darling National Wildlife Refuge | 3,130 |
| Arthur R. Marshall Loxahatchee NWR | 1,332 |
| Nisqually NWR | 487 |
| Sam D. Hamilton Noxubee NWR | 392 |
| Two Rivers National Wildlife Refuge | 392 |
| Hobe Sound NWR Nature Center (also sold at fee booth) | 350 |
| Bombay Hook National Wildlife Refuge | 217 |
| Back Bay NWR | 213 |
| St. Marks National Wildlife Refuge | 163 |
| Assabet River NWR | 106 |
| Okefenokee NWR | 105 |
| Merritt Island National Wildlife Refuge | 83 |
| DeSoto National Wildlife Refuge | 68 |
| Chincoteague NWR | 47 |
| Sacramento NWR | 36 |
| Fish and Wildlife Service Regional Office | 18 |
| National Elk Refuge | 11 |
| Don Edwards San Francisco Bay NWR | 9 |
| Parker River National Wildlife Refuge | 6 |
| Long Island NWR Complex | 4 |
| Bosque del Apache NWR | 3 |
| Ottawa National Wildlife Refuge | 3 |
| Deer Flat NWR | 2 |
| Rocky Mountain Arsenal NWR | 1 |
| Ridgefield NWRC | 1 |
| **NPS** | **108,205** |
| San Juan National Historic Site | 7,808 |
| Assateague Island National Seashore | 4,981 |
| Fort McHenry National Monument | 4,237 |
| Lake Mead National Recreation Area | 4,041 |
| Colonial National Historical Park | 3,915 |
| Hopewell Culture National Historical Park | 3,687 |
| Yosemite National Park | 3,547 |
| Channel Islands National Park | 2,983 |
| Great Falls Park | 2,980 |
| Zion National Park | 2,905 |

**5.2%**

**77.7%**

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| | |
|---|---|
| Grand Canyon National Park | 2,901 |
| Chesapeake & Ohio Canal NHP | 2,815 |
| Cuyahoga Valley National Park | 2,796 |
| Indiana Dunes National Lakeshore | 2,754 |
| Garfield National Historic Site | 2,525 |
| Chamizal National Memorial | 2,239 |
| Joshua Tree National Park | 1,987 |
| Mount Rainier National Park | 1,952 |
| Arches National Park | 1,804 |
| Rocky Mountain National Park | 1,355 |
| Acadia National Park | 1,284 |
| Tumacacori National Historical Park | 1,254 |
| San Francisco Maritime National Historical Park | 1,194 |
| Pictured Rocks National Seashore | 1,163 |
| Lewis & Clark National Historical Park | 1,114 |
| Fort Vancouver National Historic Site | 1,089 |
| Richmond National Battlefield Park | 1,081 |
| Pinnacles National Monument | 1,053 |
| Petroglyph National Monument | 1,037 |
| Harpers Ferry National Historical Park | 1,007 |
| Yellowstone National Park | 989 |
| Bents Old Fort Historic Site | 980 |
| Walnut Canyon National Monument | 962 |
| Lowell National Historical Park | 953 |
| Sequoia & Kings Canyon National Park | 837 |
| Delaware Water Gap National Rec Area | 834 |
| Death Valley National Park | 825 |
| Golden Gate NRA - Muir Woods Visitors Ctr | 795 |
| Cedar Breaks National Monument | 743 |
| Bryce Canyon National Park | 716 |
| Montezuma Castle National Monument | 696 |
| Catoctin Mountain Park | 688 |
| Blue Ridge Parkway (Campgrounds) | 688 |
| Cumberland Island National Seashore | 685 |
| Colorado National Monument | 681 |
| Petrified Forest National Park | 675 |
| Big Thicket National Preserve | 651 |
| Pu'uhonua O Honaunau | 633 |
| Sleeping Bear Dunes National Lakeshore | 572 |
| Crater Lake National Park | 566 |
| Casa Grande Ruins National Monument | 525 |
| Cabrillo National Monument | 511 |
| Wright Brothers National Memorial | 483 |
| Everglades National Park | 468 |
| Organ Pipe Cactus National Monument | 466 |

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| | |
|---|---|
| Little Rock Central High School NHS | 464 |
| Badlands National Park | 464 |
| Hawaii Volcanoes National Park | 454 |
| Castillo de San Marcos National Monument | 437 |
| Guadalupe Mountains National Park | 423 |
| Capulin Volcano National Monument | 422 |
| Olympic National Park | 414 |
| Appomattox Court House Historical Park | 400 |
| Big South Fork National River & Recreation Area | 376 |
| Carlsbad Caverns National Park | 376 |
| Canyonlands National Park | 366 |
| Amistad National Recreation Area | 353 |
| Padre Island National Seashore | 335 |
| Tonto National Monument | 333 |
| Grand Teton National Park | 325 |
| Mesa Verde National Park | 323 |
| Dinosaur National Monument (Passes only sold at UT location)) | 306 |
| Shenandoah National Park - Thornton Gap Entrance | 303 |
| Chaco Culture National Historical Park | 280 |
| Shenandoah National Park - Front Royal Entrance | 277 |
| Lava Beds National Monument | 272 |
| Gila Cliff Dwellings National Monument | 257 |
| Ulysses S Grant National Historic Site | 231 |
| Saguaro National Park | 230 |
| Florissant Fossil Beds National Monument | 226 |
| Shenandoah National Park - Swift Run Entrance | 218 |
| Bighorn Canyon National Recreation Area | 213 |
| Cape Cod National Seashore - Provincelands V.C. | 209 |
| Hot Springs National Park | 209 |
| Great Sand Dunes National Park | 208 |
| Shenandoah National Park - Rockfish Entrance | 208 |
| Chickamauga & Chattanooga National Military Park | 203 |
| Glacier National Park | 197 |
| Obed Wild and Scenic River | 192 |
| Fort Washington Park | 180 |
| Capitol Reef National Park | 178 |
| Big Bend National Park | 167 |
| Fossil Butte National Monument | 161 |
| Golden Spike National Historic Site | 158 |
| White Sands National Monument | 158 |
| Haleakala National Park | 149 |
| Weir Farm National Historic Site | 143 |
| Devils Tower National Monument | 137 |
| Mammoth Cave National Park | 130 |
| Fort Smith National Historic Site | 128 |

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| | |
|---|---|
| Lassen Volcanic National Park | 124 |
| Gulf Islands National Seashore | 120 |
| Jewel Cave National Monument | 120 |
| Brown v Board of Education National Historic Site | 119 |
| Antietam National Battlefield | 105 |
| Aztec Ruins National Monument | 101 |
| Craters of the Moon National Monument | 100 |
| Edison National Historical Park | 98 |
| Greenbelt Park | 98 |
| Bandalier National Monument | 98 |
| Prince William Forest Park | 94 |
| Sunset Crater Volcano National Monument | 93 |
| Scotts Bluff National Monument | 91 |
| Coronado National Monument | 90 |
| Saint Gaudens National Historic Site | 87 |
| Whiskeytown National Recreation Area | 82 |
| Canaveral National Seashore | 73 |
| National Historic Oregon Trail Interpretive Center | 68 |
| Timpanogos Cave National Monument | 65 |
| Rainbow Bridge National Monument (see Glen Canyon, UT) | 61 |
| Klondike Gold Rush National Historical Park | 60 |
| William Howard Taft National Historical Site | 60 |
| Glen Canyon NRA | 54 |
| Lewis & Clark NHT/NPS Midwest Regional Office | 53 |
| Steamtown National Historic Site | 51 |
| Point Reyes National Seashore | 50 |
| Chickasaw National Recreation Area | 48 |
| Wind Cave National Park | 40 |
| Mount Rushmore National Memorial | 40 |
| Cape Cod National Seashore - Salt Pond V.C. | 38 |
| Fort Union National Monument | 35 |
| Fort Moultrie National Monument | 34 |
| Great Basin National Park | 33 |
| Fort Davis National Historic Site | 30 |
| Vicksburg National Military Park | 27 |
| Pipestone National Monument | 27 |
| Wilson's Creek National Battlefield | 26 |
| Tuzigoot National Monument | 26 |
| Lincoln Boyhood National Memorial | 25 |
| Denali National Park & Preserve | 23 |
| Harry S Truman National Historic Site | 21 |
| Theodore Roosevelt National Park - South Unit | 20 |
| Wupatki National Monument | 20 |
| Little Bighorn Battlefield National Monument | 20 |
| Saratoga National Historical Park | 20 |

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| | |
|---|---|
| Pipe Spring National Monument | 18 |
| Natural Bridges National Monument | 16 |
| Mississippi National River & Recreation Area | 16 |
| Chickamauga and Chattanooga NMP- Lookout Mountain | 13 |
| Great Smoky Mountains NP - Sugarland VC | 12 |
| Great Smoky Mountains NP - Oconaluftee Visitor's Center | 10 |
| Alaska Public Lands Visitor Center - Anchorage | 7 |
| Biscayne National Park | 6 |
| Herbert Hoover National Historical Site | 5 |
| Johnstown Flood National Memorial | 5 |
| Fort Necessity National Battlefield | 4 |
| Great Smoky Mountains NP - Smokemont Campground | 3 |
| Valles Caldera National Preserve | 3 |
| Carl Sandburg Home National Historic Site | 3 |
| Great Smoky Mountain NP - Cades Cove Campground | 3 |
| Kings Mountain National Military Park | 2 |
| Isle Royale National Park | 2 |
| Homestead National Monument of America | 2 |
| Glen Canyon NRA (both AZ and UT) | 2 |
| Marsh-Billings-Rockefeller National Historical Park | 1 |
| San Antonio Missions National Historic Park | 1 |
| **USACE** | **8,223** |
| Philpott Lake | 1,349 |
| Mississippi River Project | 1,022 |
| Allatoona | 960 |
| Falls Lake | 688 |
| Wappapello Lake | 477 |
| Table Rock Lake | 412 |
| Proctor lake | 396 |
| Lake Shelbyville | 365 |
| Gull Lake Recreation Area | 360 |
| Englebright Lake | 318 |
| Raystown Lake Project | 244 |
| Sam Rayburn Lake | 235 |
| Jordan Lake | 195 |
| Sandy Lake Recreation Area | 191 |
| Carters | 175 |
| Woodruff-Seminole | 150 |
| W. Kerr Scott Dam and Reservoir | 144 |
| John H. Kerr Dam and Reservoir | 112 |
| Willamette Valley Project (Cottage Grove/Dorena) | 77 |
| Greers Ferry Lake | 60 |
| Cordell Hull Lake | 57 |
| Thurmond Project | 50 |
| Eastman Lake | 50 |

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**5.9%**

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| | |
|---|---|
| Cochiti Lake | 49 |
| Leech Lake Recreation Area | 27 |
| Gillham Lake | 23 |
| Bonneville Lock and Dam- Bradford Island Visitor Center | 13 |
| Taylorsville Lake | 5 |
| West Hill Dam | 4 |
| The Dalles Lock and Dam- Visitor Center | 3 |
| North Hartland Lake | 2 |
| Clinton Lake Project | 2 |
| Tioga-Hammond Lakes Project | 1 |
| Abiquiu Lake | 1 |
| Success Lake | 1 |
| Barren River Lake | 1 |
| Coralville Lake | 1 |
| Hensley Lake | 1 |
| Bay Model Visitor Center | 1 |
| Cowanesque Lake Project | 1 |

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**To:** Indur Goklany[indur_goklany@ios.doi.gov]
**From:** Willard, Debra
**Sent:** 2017-06-05T09:39:19-04:00
**Importance:** Normal
**Subject:** Earth's climate history briefing
**Received:** 2017-06-05T09:39:30-04:00
Earth_Climate_History_final_draft_6-1-2017.docx

Hi Goks,

I forwarded the attached document upstairs last week; I haven't received the final go-ahead on it, but I'm attaching it here for you to look over. [redacted] (b)(5)

[redacted] (b)(5)

Please let me know if you have further questions.

Best,

Deb


--------------------------------------------------------------------------------
Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

# INFORMATION/BRIEFING MEMORANDUM

DATE: June 5, 2017
FROM:
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations of past change help provide critical context for policy makers and resource managers in the Department of the Interior and other agencies to be responsible stewards for Federal lands and our Nation's treasures. These studies also provide a scientific basis to help anticipate and plan for important societal and ecological impacts of future changes in climate and land use.

**KEY TAKEAWAYS**

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the oceans and atmosphere (Figure 1).
- Over millions to hundreds-of-thousands of years, changes in climate have been governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), changes in the extent of continent-scale glaciers and sea ice, and variations in atmospheric chemistry.
- During the past ~2,600,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). Detailed records of the last 800,000 years were captured by the EPICA Dome C ice core from Antarctica and illustrate the variability in various climate and environmental parameters (Figure 2). During the Last Glacial Maximum (~ 21,000 years ago), ice sheets, more than a mile high in many places, covered substantial portions of the Northern and Southern Hemispheres. In North America they extended as far south as Illinois (Figure 3). The current interglacial began about 12,000 years ago. The previous interglacial ended approximately 114,000 years ago.
- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system caused variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes occurred, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.
- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the

Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century was benign relative to the variability seen over the previous thousand years. In particular, within the North American continent, there were multi-decadal droughts, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest) (Figure 4).

- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were much smaller than today. During the last few thousand years, variations in relative global sea level occurred due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers (Figure 5).
- For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period (Figure 6). They fluctuated between low concentrations of 190-200 parts per million volume (ppmv) during the Ice Ages to 280 ppmv during warm interglacial periods.

**Temperature Extremes**

The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years (Figure 1).

The Long-Term Geologic Record of Temperature

Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics (Figure 2). In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities. For example, during the mid-Pliocene Warm Period, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to longer glacial-interglacial time scales, air and ocean temperatures still varied considerably. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By

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**Hydrologic Extremes**

The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Records of past droughts and unusually wet periods are preserved by tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during Medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America (Figure 4). As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20th century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand years. These studies also will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are

developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**

Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth of ice sheets were the primary influence on sea level. Sea level is low during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels during the last glaciation were 125 meters (410 feet) lower than today (Figure 4).

During the last interglacial period (~125,000 years ago), sea levels were about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

Since the last Ice Age, there have been instances of rapid sea level rise due to sudden releases of meltwater from ice sheets or the bursting of ice dams (Figure 5). For example, during the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters (13 feet) per century.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example, melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that one sees depends on where and when one looks. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to local subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting causal mechanisms is a priority research area.

**Carbon Cycle Variability**

Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic

activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where 3200 meter long (nearly 2 mile) thick records span the last 800,000 years, or the last eight ice ages (Figure 2). Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released carbon from soils into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), and research is underway to determine how land-use changes since Colonial times (such as deforestation, drainage of wetlands) affected carbon storage in soils.

**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are determining how terrestrial and marine systems and their biota were affected by a broad range of changes throughout Earth history. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers

and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

# FIGURES

Figure 1 – Global deep-sea oxygen and carbon isotope records compiled from more than 40 sites around the globe indicate substantial climate variability over the last 65 million years. The present configuration of continents and oceans has been in place for approximately the last 3 million years, after closure of the Panama Seaway. The temperature scale was calculated based on an ice-free ocean and applies only to the time before onset of significant Antarctic glaciation, which began around 35 million years ago. Figure from Zachos et al., 2001.

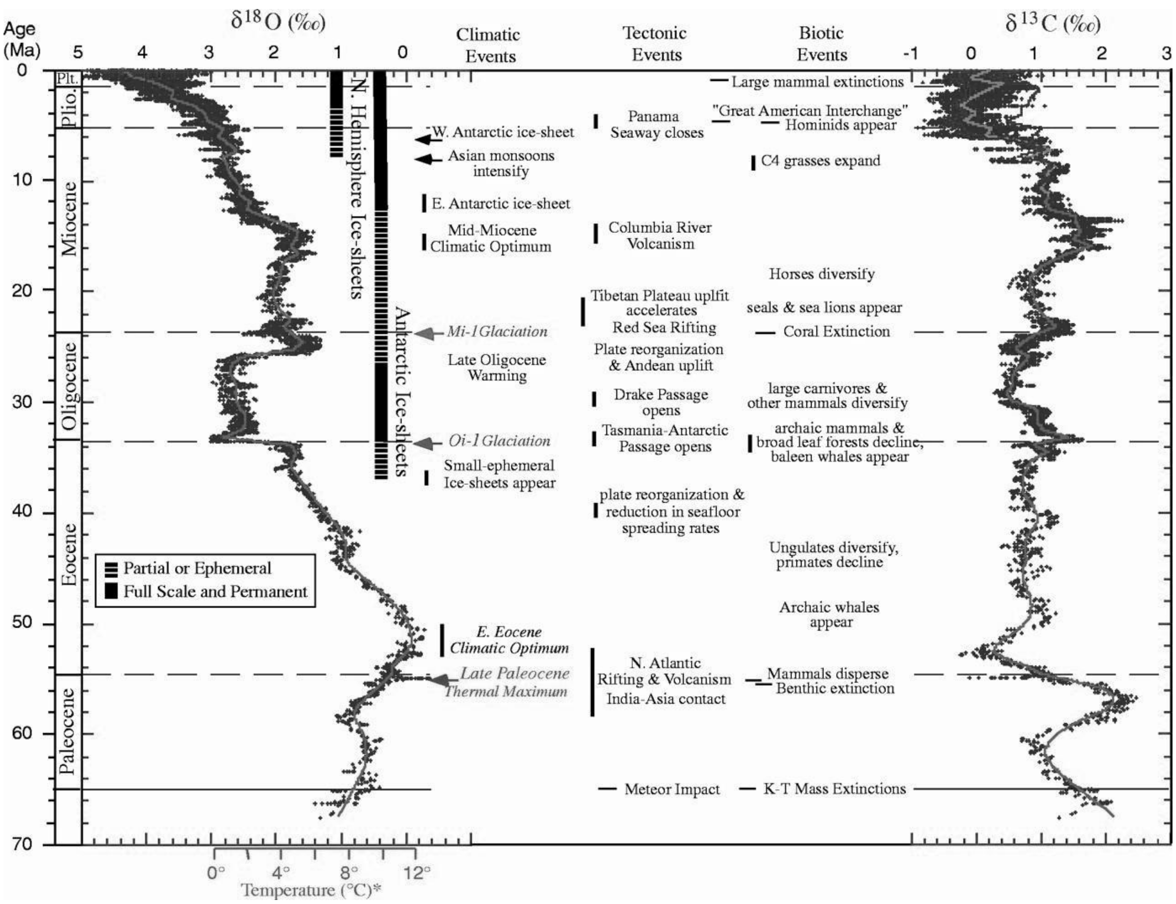


**Figure 2** – Carbon dioxide ($CO_2$), temperature, and other environmental parameters fluctuate between Ice Age (glacial) and warmer interglacial periods. This figure shows $CO_2$ records and temperature anomalies from the EPICA Dome C in Antarctica over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

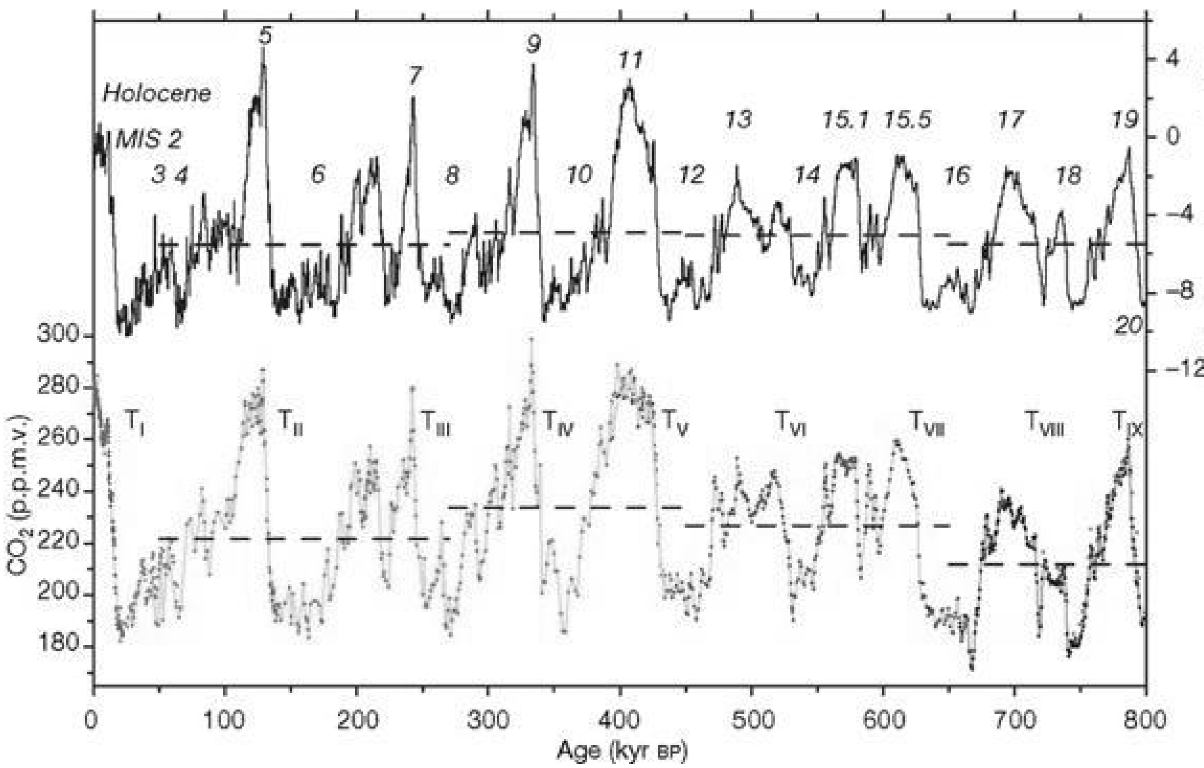


Figure 3 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum (21,000 years ago), early Holocene (11,000 years ago), mid-Holocene (7000 years ago), and the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much broader (modified from Bartlein et al., 2014).

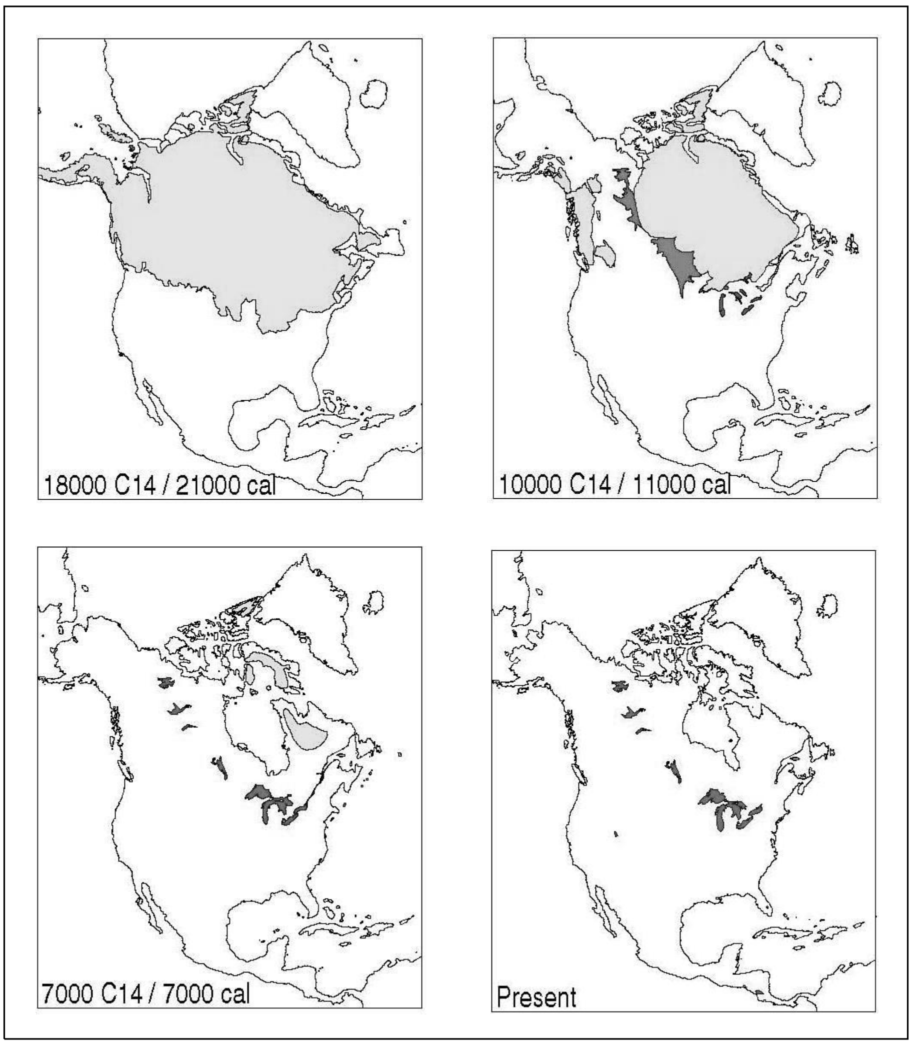


Figure 4. Reconstructed streamflow of the Colorado River at Lee Ferry from AD 762-2005 (from Meko et al., 2007). During an extended drought in the mid-1100's, mean annual streamflow decreased by more than 15%. The timing corresponds to dry conditions inferred from tree-ring and paleoclimate proxy records elsewhere in the Great Basin and Colorado Plateau.

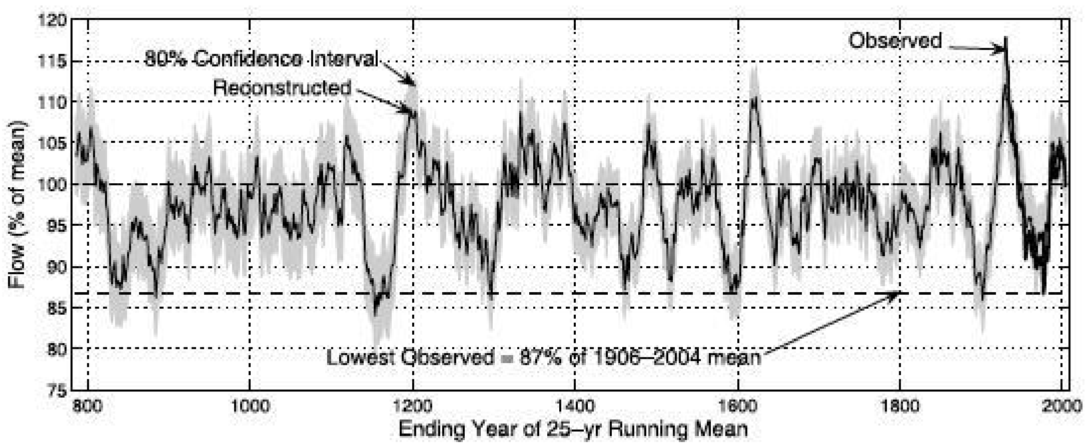


Fig. 5. Relative sea level curve for Barbados over the past 32,000 years (from Peltier et al., 2015); a relative sea level of 0 meters represents the present day. Blue bars represent sea-level index points based on four species of coral that were dated using Uranium-thorium dating (a technique that provides ages of carbonate materials such as corals over the past 500,000 years). The black curve represents a fit to the data using the ICE-6G (VM5a) model outlined in Peltier et al. (2015). The inset shows. The inset shows, in red, the eustatic sea level for the full 100,000 year glacial cycle.

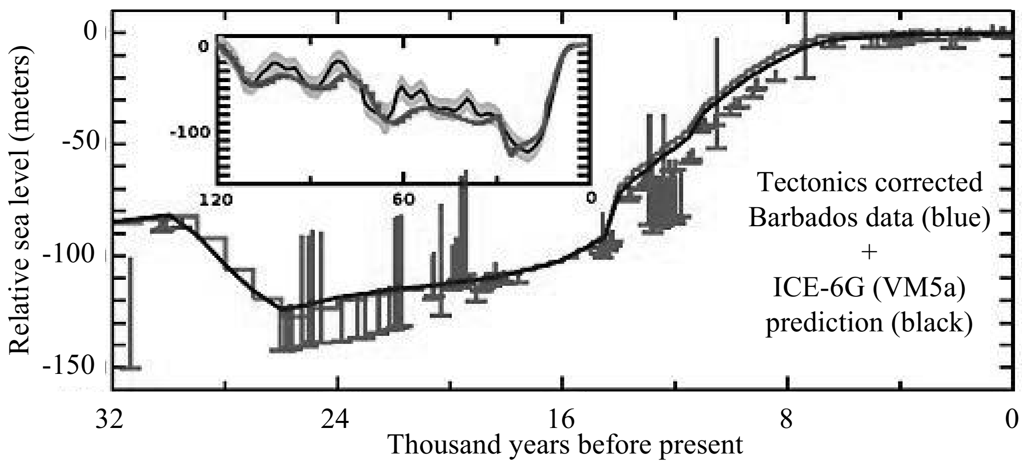
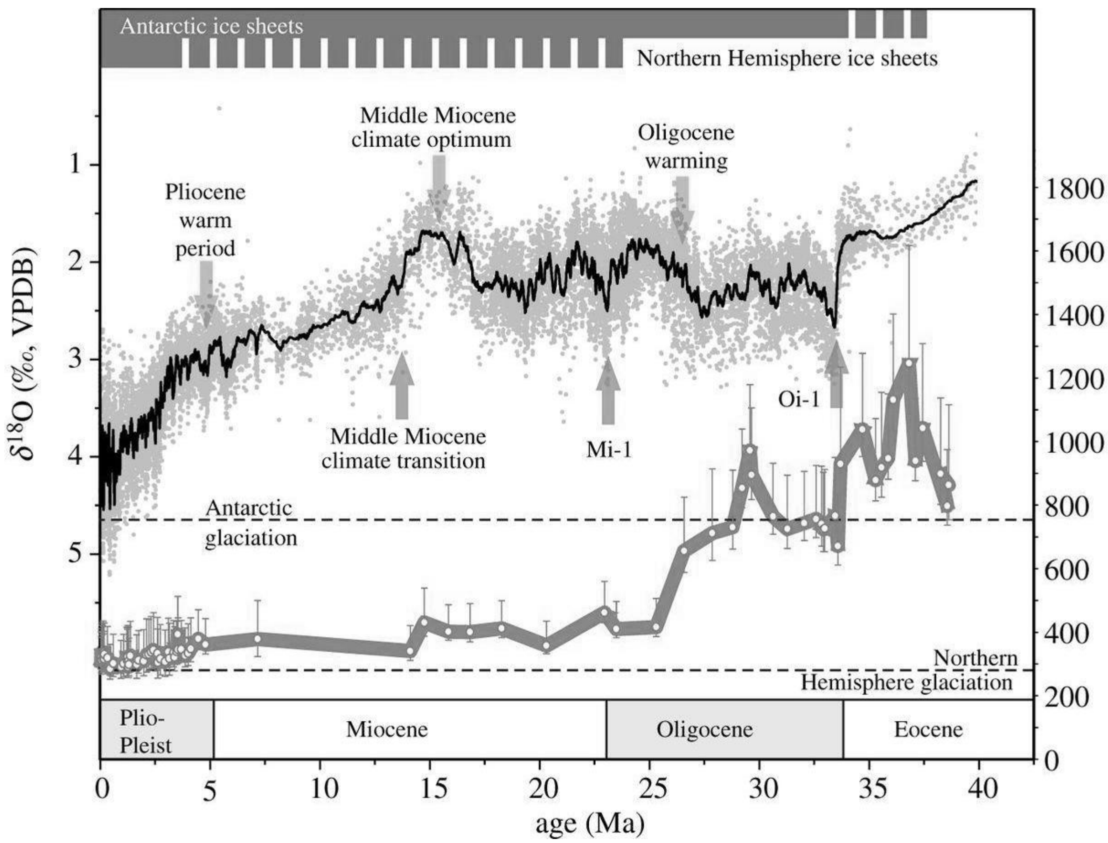


Figure 6. Climate and atmospheric $CO_2$ history for the past 40 million years. The benthic $\delta^{18}O$ curve is a stacked compilation of data from deep-sea benthic foraminifers from sites around the world from Zachos et al. (2008). Major warming (red arrows) and cooling (blue arrows) events are labelled. Red bars indicate brief history of Antarctic and Northern Hemisphere ice sheets. Antarctic glaciation thresholds (approx. 750 ppm) and Northern Hemisphere glaciation threshold (approx. 280 ppm) deduced from climate models (deConto et al., 2008) are marked by dashed lines. (Figure from Zhang et al., 2013)



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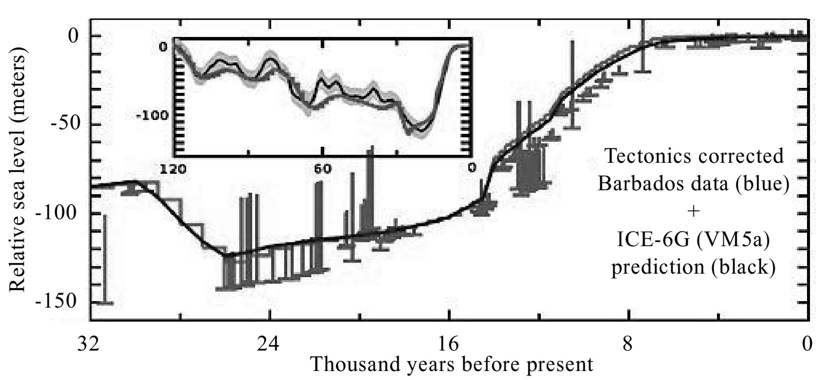

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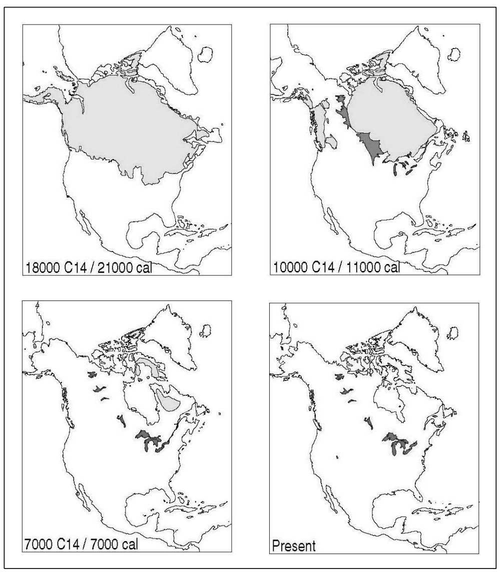

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**To:** Willard, Debra[dwillard@usgs.gov]
**From:** Goklany, Indur
**Sent:** 2017-06-05T16:00:06-04:00
**Importance:** Normal
**Subject:** Re: Earth's climate history briefing
**Received:** 2017-06-05T16:00:48-04:00
Earth_Climate_History_final_draft_6-1-2017.ig.docx

Debra,

[redacted]

I was going to call but didn't have your home number.

In the attached, I have made changes that we discussed, but not to Figure 5 given that may be replaced.

Thanks.

Goks

On Mon, Jun 5, 2017 at 2:23 PM, Willard, Debra <dwillard@usgs.gov> wrote:

Peltier_et_al-2015-Journal_of_Geophysical_Resea...

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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
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Reston, VA 20192
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e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 2:03 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Hi Debra-- I just called you but you weren't in. Call me when you can. Thanks -- Goks (202-208-4951)

On Mon, Jun 5, 2017 at 9:39 AM, Willard, Debra <dwillard@usgs.gov> wrote:

Hi Goks,

I forwarded the attached document upstairs last week; I haven't received the final go-ahead on it, but I'm attaching it here for you to look over. Please consider it a near-final draft, and note that I have left the

"From" line blank until I get further instructions. [redacted] (b)(5)
[redacted] (b)(5) I'll let you know once I get a final answer.

I addressed your comments and questions in the text, and I also substituted some figures from more recent publications. The references cited are tied to the figures only. In the interest of conserving space, I did not include citations in the text, but I can provide those if needed.

Please let me know if you have further questions.

Best,

Deb

--------------------------------------------------------------------------------
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**Hydrologic Extremes**
The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Past droughts and unusually wet periods can be inferred using tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

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To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during Medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America (Figure 4). As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20th century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand years. These studies also will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are

developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**
Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth of ice sheets were the primary influence on sea level. Sea level is low during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels during the last glaciation were 125 meters (410 feet) lower than today (Figure 4).

During the last interglacial period (~125,000 years ago), sea levels were about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

Since the last Ice Age, there have been instances of rapid sea level rise due to sudden releases of meltwater from ice sheets or the bursting of ice dams (Figure 5). For example, during the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters (13 feet) per century.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example, melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that one sees depends on where and when one looks. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to local subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting causal mechanisms is a priority research area.

**Carbon Cycle Variability**
Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic

activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where 3200 meter long (nearly 2 mile) thick records span the last 800,000 years, or the last eight ice ages (Figure 2). Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released carbon from soils into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), and research is underway to determine how land-use changes since Colonial times (such as deforestation, drainage of wetlands) affected carbon storage in soils.

**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are determining how terrestrial and marine systems and their biota were affected by a broad range of changes throughout Earth history. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers

and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

## FIGURES

Figure 1 – Global deep-sea oxygen and carbon isotope records compiled from more than 40 sites around the globe indicate substantial climate variability over the last 65 million years. The present configuration of continents and oceans has been in place for approximately the last 3 million years, after closure of the Panama Seaway. The temperature scale was calculated based on an ice-free ocean and applies only to the time before onset of significant Antarctic glaciation, which began around 35 million years ago. Figure from Zachos et al., 2001.

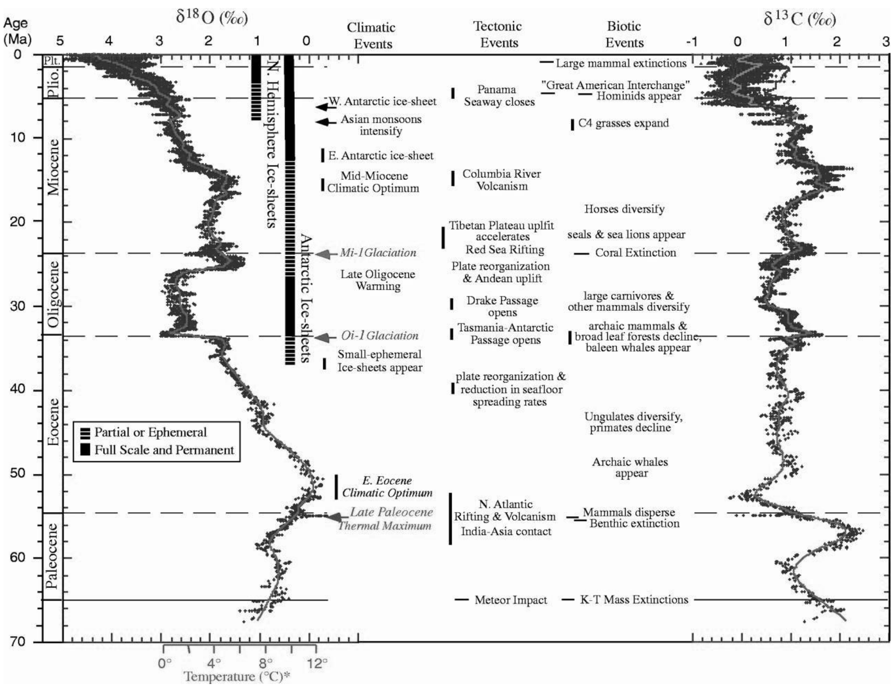


**Figure 2** – Carbon dioxide ($CO_2$), temperature, and other environmental parameters fluctuate between Ice Age (glacial) and warmer interglacial periods. This figure shows $CO_2$ records and temperature anomalies from the EPICA Dome C in Antarctica over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

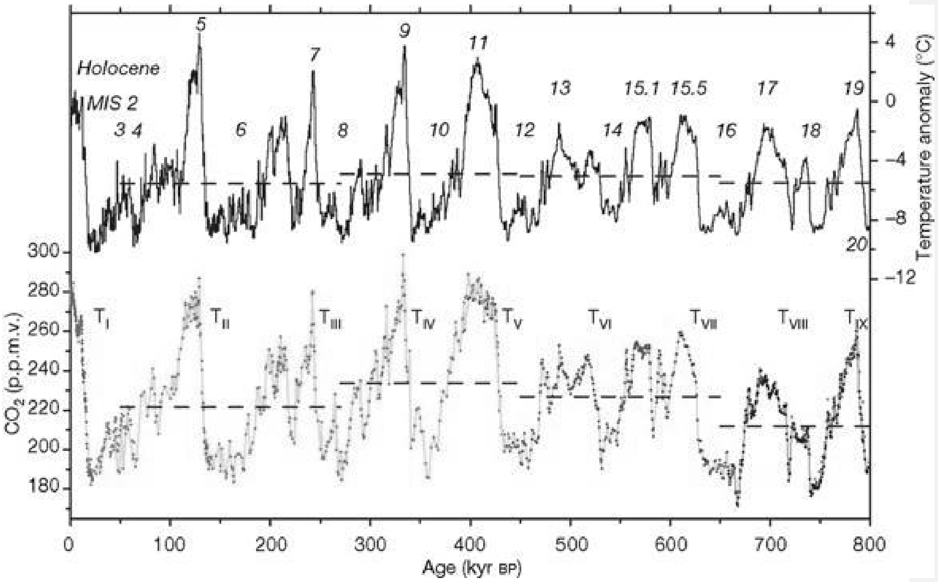


Figure 3 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum (21,000 years ago), early Holocene (11,000 years ago), mid-Holocene (7000 years ago), and the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much broader (modified from Bartlein et al., 2014).

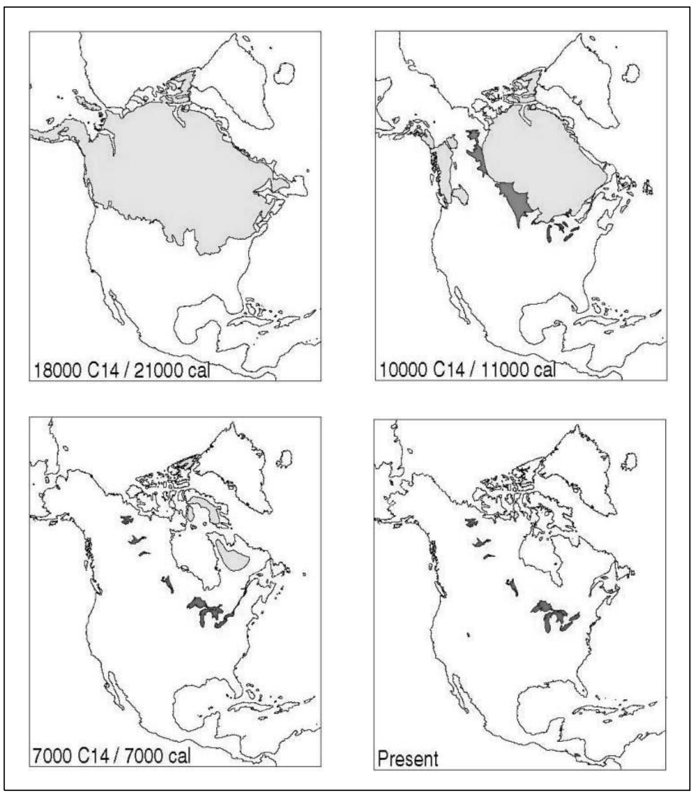


Figure 4. Reconstructed 25-year mean streamflow of the Colorado River at Lee Ferry from AD 762-2005 (from Meko et al., 2007). The 100% flow level corresponds to the 1906-2004 mean. During an extended drought in the mid-1100's, mean annual streamflow decreased by more than 15%. The lowest 25-year mean for the observed period was for 1953-1977, at 87%.

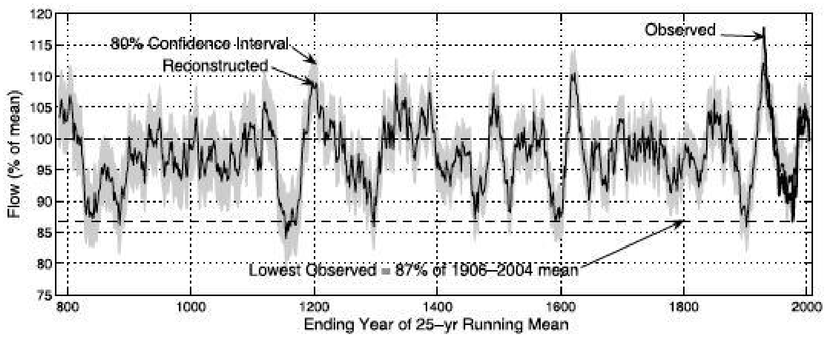


Fig. 5. Relative sea level curve for Barbados over the past 32,000 years (from Peltier et al., 2015); a relative sea level of 0 meters represents the present day. Blue bars represent sea-level index points based on four species of coral that were dated using Uranium-thorium dating (a technique that provides ages of carbonate materials such as corals over the past 500,000 years). The black curve represents a fit to the data using the ICE-6G (VM5a) model outlined in Peltier et al. (2015). The inset shows. The inset shows, in red, the eustatic sea level for the full 100,000 year glacial cycle.

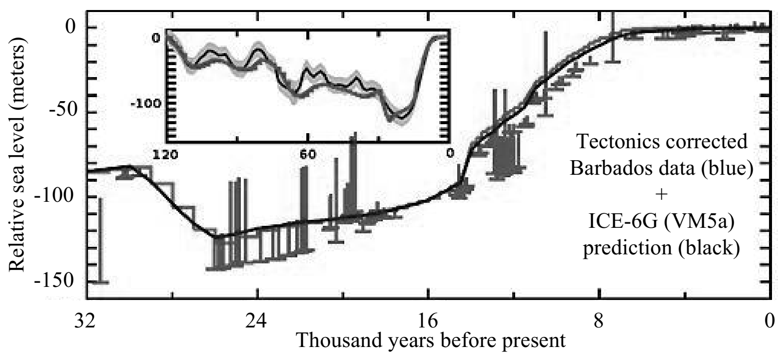
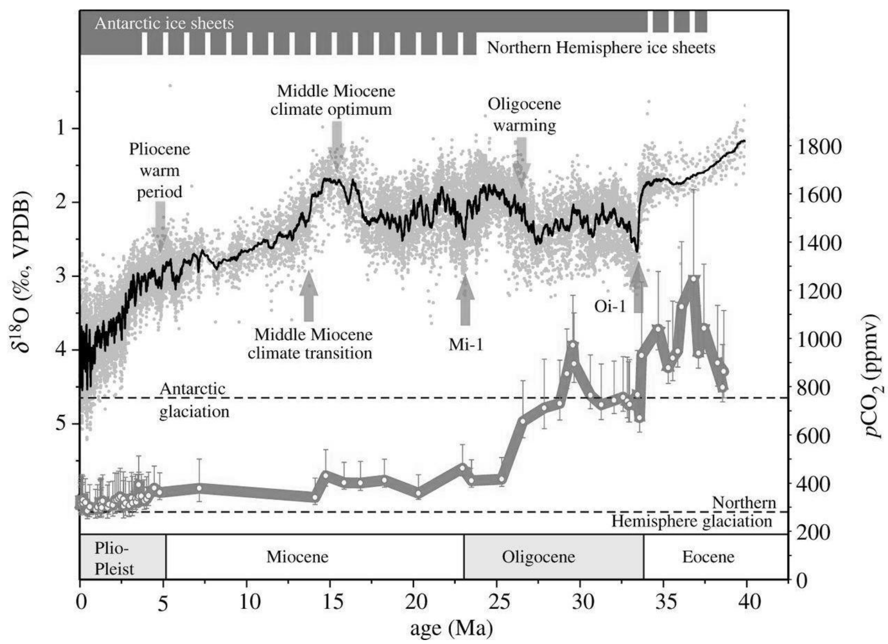


Figure 6. Climate and atmospheric $CO_2$ history for the past 40 million years. The benthic $\delta^{18}O$ curve is a stacked compilation of data from deep-sea benthic foraminifers from sites around the world from Zachos et al. (2008). Major warming (red arrows) and cooling (blue arrows) events are labelled. Red bars indicate brief history of Antarctic and Northern Hemisphere ice sheets. Antarctic glaciation thresholds (approx. 750 ppm) and Northern Hemisphere glaciation threshold (approx. 280 ppm) deduced from climate models (deConto et al., 2008) are marked by dashed lines. (Figure from Zhang et al., 2013)



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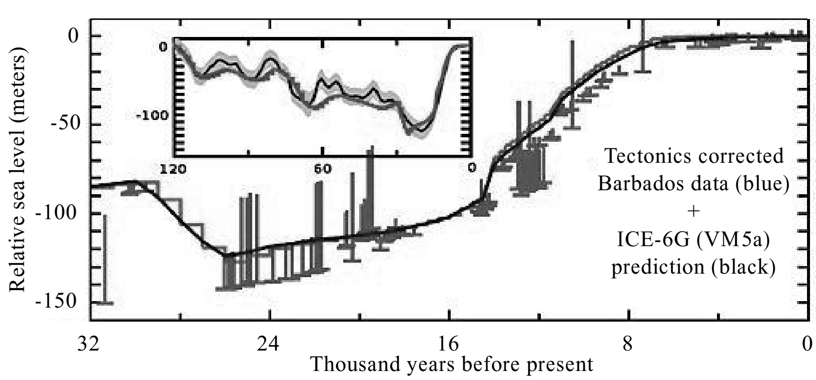

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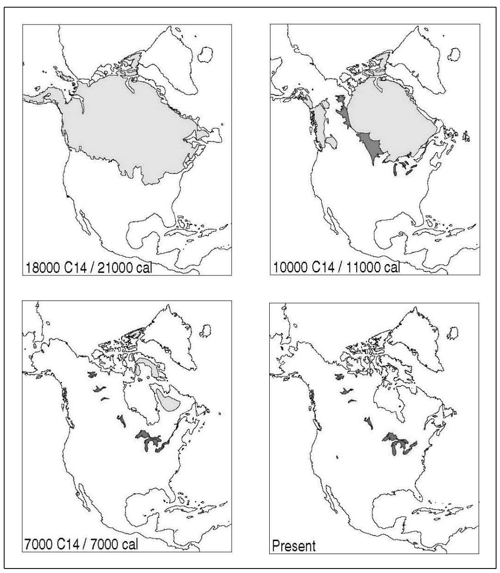

**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**Cc:** Judy Nowakowski[jnowakowski@usgs.gov]; Virginia Burkett[virginia_burkett@usgs.gov]
**From:** Willard, Debra
**Sent:** 2017-06-06T11:46:24-04:00
**Importance:** Normal
**Subject:** Re: Earth's climate history briefing
**Received:** 2017-06-06T11:46:28-04:00
Earth_Climate_History_final_clean_draft_6-6-17.docx

Hi Goks,
I've attached the revised briefing document. [redacted] (b)(5)

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Thanks for your helpful comments; I enjoyed pulling this together.

Regards,

Deb

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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 7:24 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

[redacted] Let's continue this tomorrow. Thanks

On Mon, Jun 5, 2017 at 5:07 PM, Willard, Debra <dwillard@usgs.gov> wrote:

[redacted]

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Coordinator, Climate Research & Development Program
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926A National Center
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e-mail: dwillard@usgs.gov
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On Mon, Jun 5, 2017 at 4:00 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Debra,

[redacted]

I was going to call but didn't have your home number.

In the attached, I have made changes that we discussed, but not to Figure 5 given that may be replaced.

Thanks.

Goks

On Mon, Jun 5, 2017 at 2:23 PM, Willard, Debra <dwillard@usgs.gov> wrote:

**Peltier_et_al-2015-Journal_of_Geophysical_Resea...**

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phone:   703-648-5320
e-mail:  dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 2:03 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

> Hi Debra-- I just called you but you weren't in. Call me when you can. Thanks -- Goks (202-208-4951)

On Mon, Jun 5, 2017 at 9:39 AM, Willard, Debra <dwillard@usgs.gov> wrote:

Hi Goks,

I forwarded the attached document upstairs last week; I haven't received the final go-ahead on it, but I'm attaching it here for you to look over. Please consider it a near-final draft, and note that I have left the "From" line blank until I get further instructions [redacted] I'll let you know once I get a final answer.

I addressed your comments and questions in the text, and I also substituted some figures from more recent publications. The references cited are tied to the figures only. In the interest of conserving space, I did not include citations in the text, but I can provide those if needed.

Please let me know if you have further questions.

Best,

Deb

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e-mail:  dwillard@usgs.gov
https://profile.usgs.gov/dwillard

# INFORMATION/BRIEFING MEMORANDUM

DATE: June 5, 2017
FROM: Bill Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations of past change help provide critical context for policy makers and resource managers in the Department of the Interior and other agencies to be responsible stewards for Federal lands and our Nation's treasures. These studies also provide a scientific basis to help anticipate and plan for important societal and ecological impacts of future changes in climate and land use. This document summarizes geologic evidence for changes in temperature, water availability, sea level, ice cover, and carbon cycling over a range of temporal and spatial scales.

**KEY TAKEAWAYS**

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the oceans and atmosphere (Figure 1).
- Over millions to hundreds-of-thousands of years, changes in climate have been governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), changes in the extent of continent-scale glaciers and sea ice, and variations in atmospheric chemistry.
- During the past ~2,600,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). Detailed records of the last 800,000 years were captured by the EPICA Dome C ice core from Antarctica and illustrate the variability in various climate and environmental parameters (Figure 2). During the Last Glacial Maximum (~ 21,000 years ago), ice sheets, more than a mile high in many places, covered substantial portions of the Northern and Southern Hemispheres. In North America they extended as far south as Illinois (Figure 3). The current interglacial began about 12,000 years ago. The previous interglacial ended approximately 114,000 years ago.
- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system caused variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes occurred, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.

- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century showed minor variability relative to that of the previous thousand years. During that period, within the North American continent, there were multi-decadal droughts, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest) (Figure 4).
- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were smaller than today. During the last few thousand years, variations in relative global sea level occurred due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers (Figure 5).
- For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period (Figure 6). They fluctuated between low concentrations of 190-200 parts per million volume (ppmv) during glacial periods to 280 ppmv during warm interglacial periods.

**Temperature Extremes**

The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years (Figure 1).

The Long-Term Geologic Record of Temperature

Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics (Figure 2). In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities. For example, during the mid-Pliocene Warm Period, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to longer glacial-interglacial time scales, air and ocean temperatures still varied considerably. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of

warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By conducting research at sites throughout North America, USGS scientists aim to determine when these changes began and ended, how widespread they were, and how they influenced ecosystems and natural resources.

Instrumental Records of Temperature
Instrumental measurements of land and sea surface temperatures have been collected since 1854 (toward the end of the Little Ice Age), and the National Oceanographic and Atmospheric Administration (NOAA) has calculated global averages dating from 1880. Typically, temperature anomalies are calculated relative to a 1981-2010 base period or, in the case of global averages, to the 20$^{th}$ century average. Many other surface temperature datasets and analyses are available at NOAA's National Climate Data Center. Historical temperature patterns also are presented by NASA's Goddard Institute for Space Studies (GISS) in a dataset called Surface Temperature Analysis (GISTEMP). This record indicates that the Earth's average surface temperature has warmed by about 1.1 degree Celsius (2˚ F) since the first widely-dispersed instrumental records became available in the year 1880.

**Hydrologic Extremes**
The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Past droughts and unusually wet periods can be inferred using tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during Medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America (Figure 4). As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20$^{th}$ century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand years. These studies also will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are

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Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic

activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where 3200 meter long (nearly 2 mile thick) ice core records span the last 800,000 years, or the last eight ice ages (Figure 2). Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released carbon from soils into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), and research is underway to determine how land-use changes since Colonial times (such as deforestation, drainage of wetlands) affected carbon storage in soils.

**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are determining how terrestrial and marine systems and their biota were affected by a broad range of changes throughout Earth history. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers

and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

**CONTACT**: Debra Willard, Program Coordinator for Climate and Land Use Change Research and Development, 703-648-5320, dwillard@usgs.gov

# FIGURES

Figure 1 – Global deep-sea oxygen and carbon isotope records compiled from more than 40 sites around the globe indicate substantial climate variability over the last 65 million years. The present configuration of continents and oceans has been in place for approximately the last 3 million years, after closure of the Panama Seaway. The temperature scale was calculated based on an ice-free ocean and applies only to the time before onset of significant Antarctic glaciation, which began around 35 million years ago. Figure from Zachos et al., 2001.

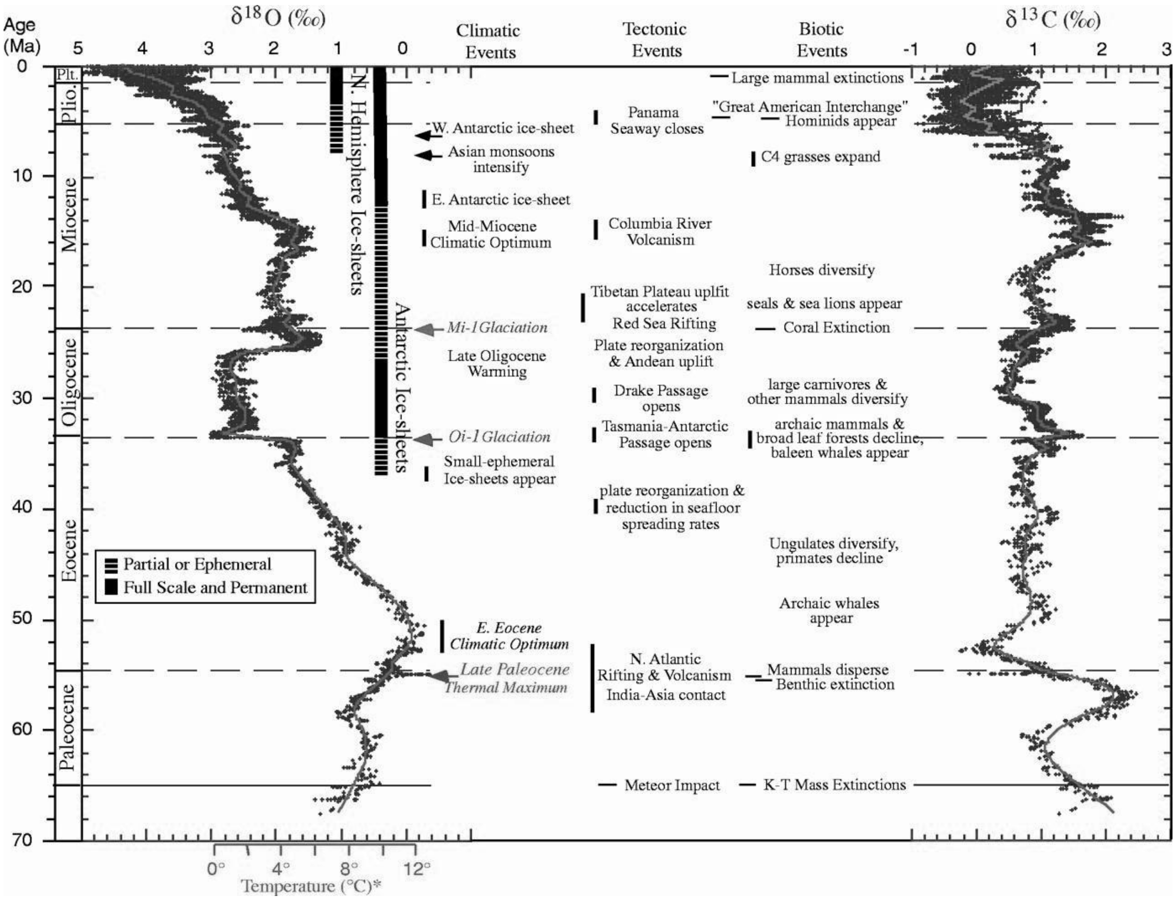


**Figure 2** – Carbon dioxide ($CO_2$), temperature, and other environmental parameters fluctuate between Ice Age (glacial) and warmer interglacial periods. This figure shows $CO_2$ records and temperature anomalies from the EPICA Dome C in Antarctica over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

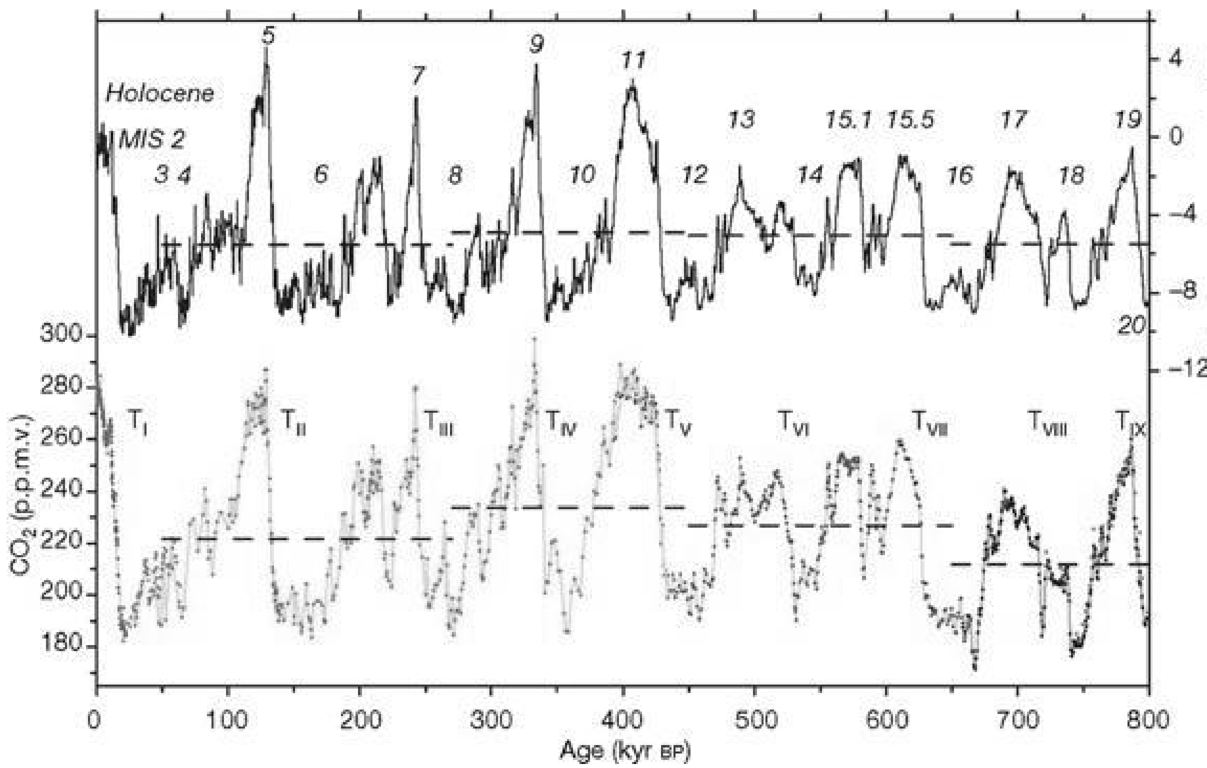


Figure 3 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum (21,000 years ago), early Holocene (11,000 years ago), mid-Holocene (7000 years ago), and the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much more extensive (modified from Bartlein et al., 2014).

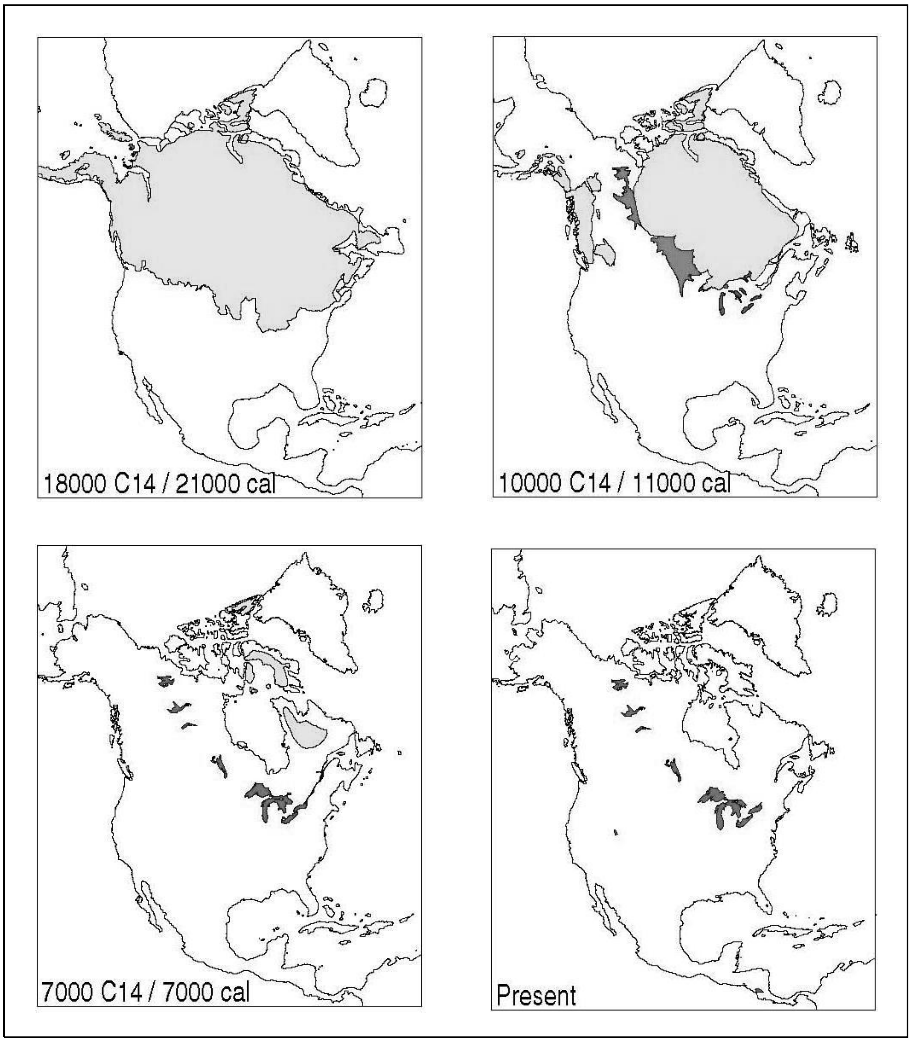


Figure 4. Reconstructed 25-year mean streamflow of the Colorado River at Lee Ferry from AD 762-2005, plotted as percentage of the 1906-2004 mean of observed natural flows, with the 100% flow level equaling the 1906-2004 mean (from Meko et al., 2007). During an extended drought in the mid-1100's, mean annual streamflow decreased by more than 15%. The horizontal dashed line (at 87%) represents the lowest 25-year mean for the observed period (1906-2004), which corresponds to the period from 1953-1977.

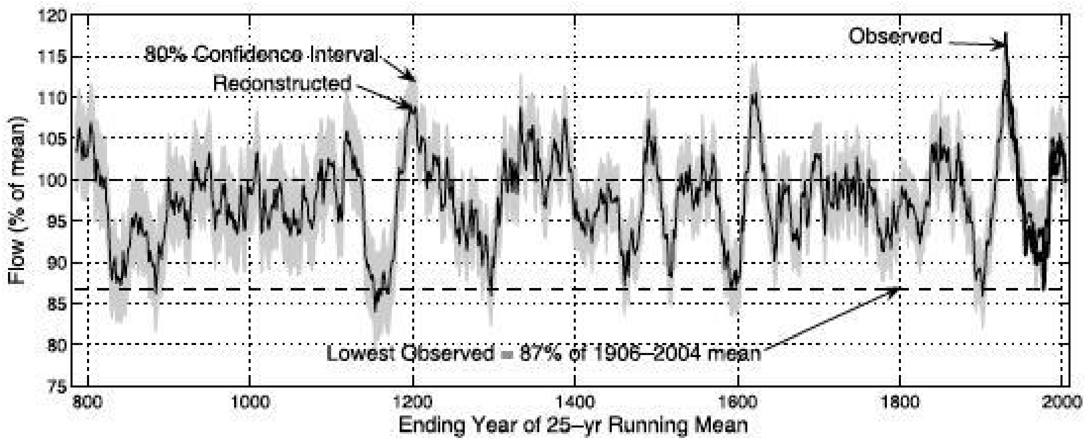


Fig. 5. Relative sea level curve for Barbados over the past 32,000 years (from Peltier et al., 2015), showing rise in sea level as the extensive ice sheets of the last Ice Age melted between about 17,000 to 8,000 years ago (a relative sea level of 0 meters represents the present day). Green bars represent sea-level index points based on four species of coral that were dated using Uranium-thorium dating (a technique that provides ages of carbonate materials such as corals over the past 500,000 years).

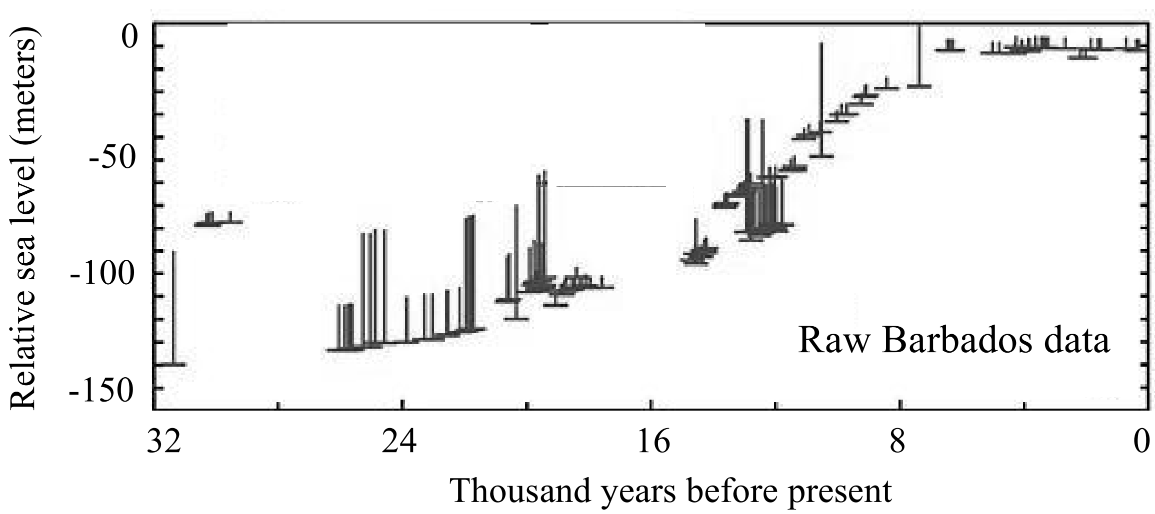
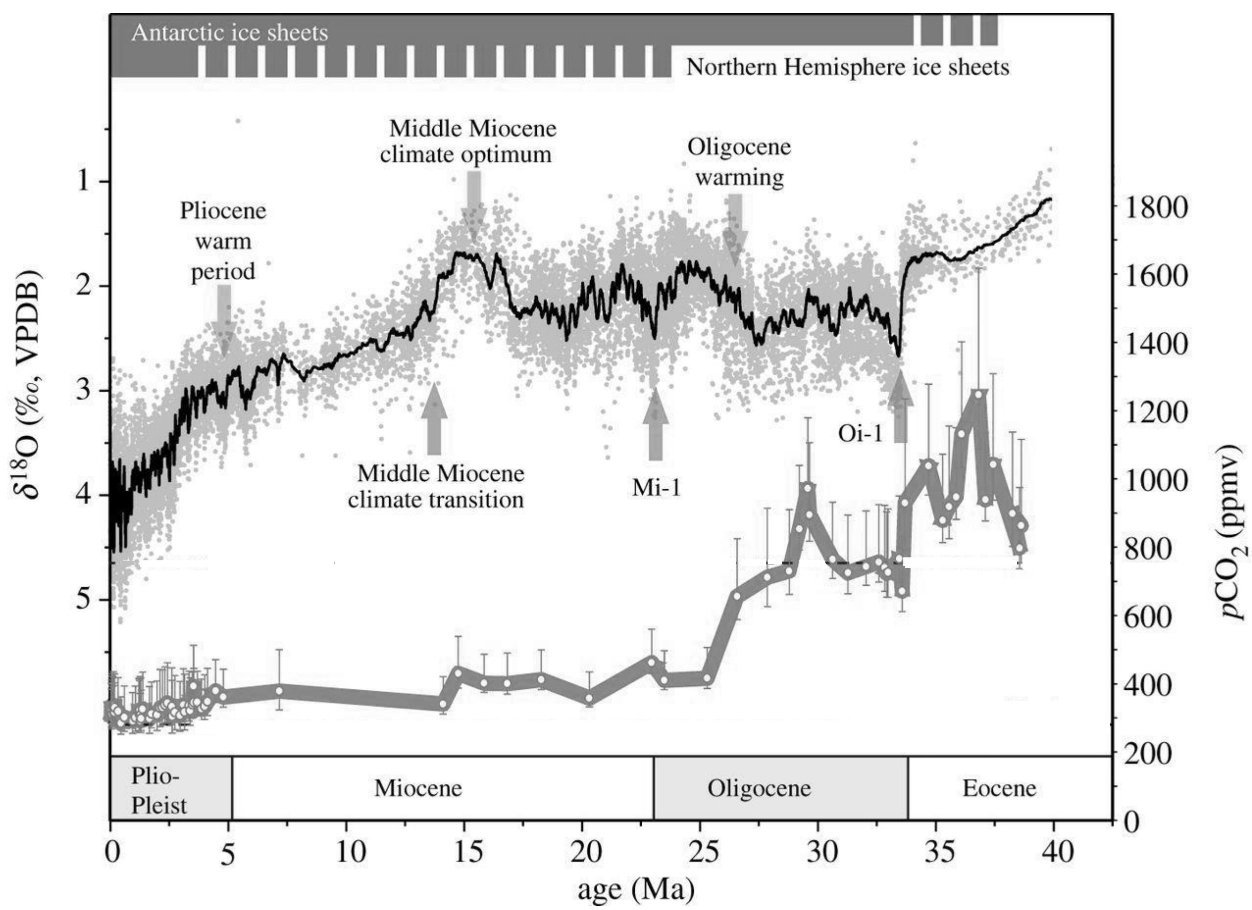


Figure 6. Climate and atmospheric $CO_2$ history for the past 40 million years. The benthic $\delta^{18}O$ curve is a stacked compilation of data from deep-sea benthic foraminifers from sites around the world and is correlated with changes in ocean temperature (from Zachos et al., 2008). The $pCO_2$ (partial pressure of atmospheric $CO_2$) reconstruction is based on measurements of alkenones (organic molecules produced by some species of marine algae) from Ocean Drilling Program Site 925 on Ceara Rise in the western equatorial Atlantic Ocean. Major warming (red arrows) and cooling (blue arrows) events are labelled. Red bars indicate brief history of Antarctic and Northern Hemisphere ice sheets. (Figure modified from Zhang et al., 2013)



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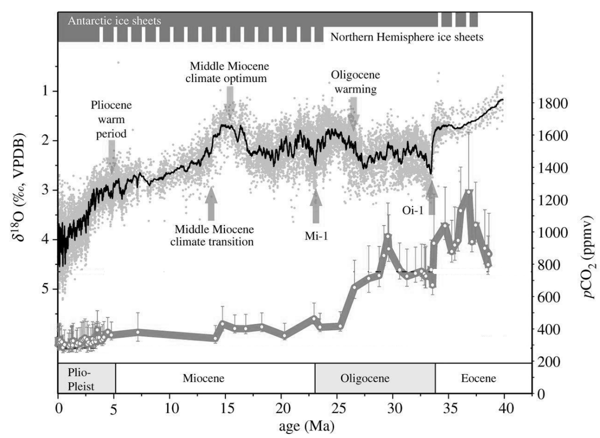
17-01174_012969;17-01174_012969



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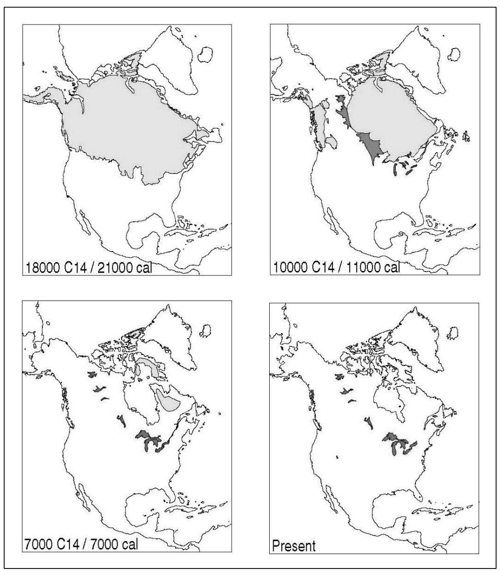

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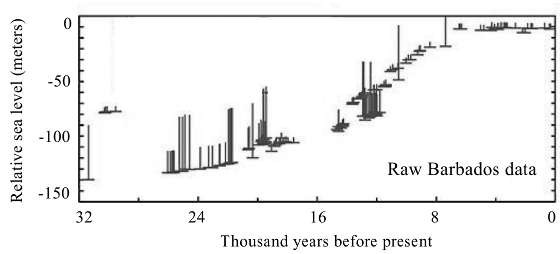

17-01174_012972;17-01174_012972;17-01174_012973;17-01174_012974

**To:** Willard, Debra[dwillard@usgs.gov]
**From:** Goklany, Indur
**Sent:** 2017-06-06T16:10:12-04:00
**Importance:** Normal
**Subject:** Re: Earth's climate history briefing
**Received:** 2017-06-06T16:11:09-04:00

Thanks Debra. I'll get you some comments to you tomorrow. [redacted] (b)(5) I'll take a crack at it and get back to you.
Regards,
Goks

On Tue, Jun 6, 2017 at 11:46 AM, Willard, Debra <dwillard@usgs.gov> wrote:

Hi Goks,
I've attached the revised briefing document. [redacted] (b)(5)

(b)(5)

Thanks for your helpful comments; I enjoyed pulling this together.

Regards,

Deb

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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192

phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 7:24 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

[redacted] Let's continue this tomorrow. Thanks

On Mon, Jun 5, 2017 at 5:07 PM, Willard, Debra <dwillard@usgs.gov> wrote:

[redacted]

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US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 4:00 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Debra,

[redacted]

I was going to call but didn't have your home number.

In the attached, [redacted]

Thanks.

Goks

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**Peltier_et_al-2015-Journal_of_Geophysical_Resea...**

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Reston, VA 20192
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e-mail:  dwillard@usgs.gov
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e-mail:  dwillard@usgs.gov
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**To:** Willard, Debra[dwillard@usgs.gov]
**Cc:** Judy Nowakowski[jnowakowski@usgs.gov]; Virginia Burkett[virginia_burkett@usgs.gov]
**From:** Goklany, Indur
**Sent:** 2017-06-07T11:25:29-04:00
**Importance:** Normal
**Subject:** Re: Earth's climate history briefing
**Received:** 2017-06-07T11:25:58-04:00
Earth_Climate_History_final_clean_draft_6-6-17.ig.docx

Debra,
My comments are on the attached. [redacted]

Thanks. I also have enjoyed working on thsi and learning something new.

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phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

17-01174_012975;17-01174_012975;17-01174_012976;17-01174_012977;17-01174_012978

# INFORMATION/BRIEFING MEMORANDUM

DATE: June 5, 2017
FROM: Bill Werkheiser, Acting Director, U.S. Geological Survey
SUBJECT: Earth's climate history

Climate, the land surface, and oceans have undergone continual changes throughout Earth's history. These changes are clearly seen in the geologic record, which provides insights on past rates and magnitudes of change, the causes of those changes, and their effects on life, water, and natural resources. Scientific investigations of past change help provide critical context for policy makers and resource managers in the Department of the Interior and other agencies to be responsible stewards for Federal lands and our Nation's treasures. These studies also provide a scientific basis to help anticipate and plan for important societal and ecological impacts of future changes in climate and land use. This document summarizes geologic evidence for changes in temperature, water availability, sea level, ice cover, and carbon cycling over a range of temporal and spatial scales.

**KEY TAKEAWAYS**

- The climate of the earth has been changing continuously since the formation of the planet and will continue to do so.
- Over very long time scales (tens to hundreds of millions of years), global climate has been shaped by changes in the amount of energy put out by the sun; the size, shape, topography and positions of continents; and changes in the chemical composition of the oceans and atmosphere (Figure 1).
- Over millions to hundreds-of-thousands of years, changes in climate have been governed by fluctuations in the distribution of sunlight across the globe (as determined by changes in the tilt of the Earth on its axis and in the shape of its orbit around the sun), changes in the extent of continent-scale glaciers and sea ice, and variations in atmospheric chemistry.
- During the past ~2,600,000 years, these changes have resulted in an alternating pattern of Ice Ages (glacial periods) and warmer climates (such as the current interglacial period). Detailed records of the last 800,000 years were captured by the EPICA Dome C ice core from Antarctica and illustrate the variability in various climate and environmental parameters (Figure 2). During the Last Glacial Maximum (~ 21,000 years ago), ice sheets, more than a mile high in many places, covered substantial portions of the Northern and Southern Hemispheres. In North America they extended as far south as Illinois (Figure 3). The current interglacial began about 12,000 years ago. The previous interglacial ended approximately 114,000 years ago.
- Over shorter time scales (thousands to tens of years) within the current interglacial, the internal dynamics of the climate system caused variations in temperature and rainfall over years, decades, and centuries. Key questions are how rapidly those changes occurred, how large they were, and how large an area was affected. These patterns provide a baseline for comparison with the Industrial era.
- Under past warmer-than-modern climates, there were major changes in the distributions of plant and animal species, and many parts of North America were much drier than present for intervals lasting decades to millennia, while others were wetter.

- Much of our understanding of climate variability and change is based on instrumental data collected during the 20th Century, a period that includes times of great heat and drought (such as the dust bowl years of the 1930s) and large-scale flooding (such as those in the Upper Midwest during the 1990s). Although these climatic events are noteworthy, information from geologic studies show that the climate of the 20th Century showed minor variability relative to that of the previous thousand years. During that period, within the North American continent, there were multi-decadal droughts, creating desert-like conditions on the High Plains and perhaps leading to large impacts on native societies (such as the Pueblo Indians of the Southwest) (Figure 4).
- Sea level was as much as 8.5 meters (27 feet) higher during the Last Interglacial period (125,000 years ago), when Greenland and Antarctic Ice Sheets were smaller than today. During the last few thousand years, variations in relative global sea level occurred due to fluctuations in temperature, ocean circulation, and melting/growth of glaciers (Figure 5).
- For much of Earth's existence, atmospheric concentrations of carbon dioxide were higher than they are currently (~ 400 ppm), a level last crossed ~ 3 million years ago, during the mid-Pliocene Warm Period (Figure 6). They fluctuated between low concentrations of 190-200 parts per million volume (ppmv) during glacial periods to 280 ppmv during warm interglacial periods.

**Temperature Extremes**
The geological record indicates large changes in air and ocean temperatures over all timescales: year-to-year changes, often associated with El Niño events; changes that operate over several decades, such as oscillations in the surface temperatures of the Pacific and Atlantic Oceans; ice age cycles over tens to hundreds of thousands of years; and very long-term climate changes over hundreds of millions of years (Figure 1).

<u>The Long-Term Geologic Record of Temperature</u>
Over very long time scales, average Earth temperatures have varied considerably. During a typical ice age of the last million years, average earth temperatures fell by as much as 5 degrees Celsius (~10˚ F), with cooling greater in polar regions than in the tropics (Figure 2). In contrast, during a warmer than modern interval about 3 million years ago (the mid-Pliocene Warm Period), global average temperatures were as much as 3 degrees Celsius (5.5˚ F) warmer than the 1951-1980 average. Such changes had large impacts on the distribution of plant and animal communities. For example, during the mid-Pliocene Warm Period, grasslands were more extensive than today, reaching farther north, while cold tundra vegetation was greatly reduced. Under the warmer and moister climate, subtropical taxa reached rather north, polar ice sheets were reduced significantly, and sea level was up to 25 meters (82 feet) higher than today. These data provide an example of the possible impacts of warmer climate, and scientists seek to acquire data from other sites to better understand the details of the warming and to improve capabilities of models to simulate conditions much different from today.

New and improved techniques allow scientists to reconstruct how past temperature, rainfall, streamflow and other factors varied over shorter time intervals (years to decades) during the last few thousand years. Although the variability over the past 2,000 years is small compared to longer glacial-interglacial time scales, air and ocean temperatures still varied considerably. For example, during Medieval times from about ~800 to 1200 years ago, a sustained period of

warmth is evident, especially in parts of Europe and elsewhere. Later, during the Little Ice Age (AD 1500-1850), many regions cooled; glaciers advanced in many parts of the world, although the advances in regions like Europe, North and South America did not occur synchronously. By conducting research at sites throughout North America, USGS scientists aim to determine when these changes began and ended, how widespread they were, and how they influenced ecosystems and natural resources.

Instrumental Records of Temperature

Instrumental measurements of land and sea surface temperatures have been collected since 1854 (toward the end of the Little Ice Age), and the National Oceanographic and Atmospheric Administration (NOAA) has calculated global averages dating from 1880. Typically, temperature anomalies are calculated relative to a 1981-2010 base period or, in the case of global averages, to the 20$^{th}$ century average. Many other surface temperature datasets and analyses are available at NOAA's National Climate Data Center. Historical temperature patterns also are presented by NASA's Goddard Institute for Space Studies (GISS) in a dataset called Surface Temperature Analysis (GISTEMP). This record indicates that the Earth's average surface temperature has warmed by about 1.1 degree Celsius (2˚ F) since the first widely-dispersed instrumental records became available in the year 1880.

**Hydrologic Extremes**

The amount of rainfall or snow that occurs at a given place varies over seasons, years, and longer time scales and is related to the position of the Earth relative to the sun. Past droughts and unusually wet periods can be inferred using tree rings and other archives contained in sediments deposited in lakes, wetlands, and oceans. Taken together, these data allow scientists to reconstruct changes in the availability of fresh water over years, centuries, and even millions of years.

To understand the severity and impacts of natural drought events over the last few thousand years, scientists are examining geologic records that are sensitive to changes in precipitation. Some droughts were nearly continental in scale, whereas others were restricted to the western United States. Some droughts lasted only a few years, and others lasted for a decade or more. Evidence from multiple geologic archives indicates that, during Medieval times around 1,000 years ago, a series of droughts that each lasted a decade or more affected much of North America (Figure 4). As a result, lake levels dropped significantly, western grasslands shifted to desert, and animal populations moved to find more suitable habitats. During one decade-long drought from AD 1146-1155, tree-ring records from the Colorado River basin indicate that stream flow in the river was reduced by one-fifth, relative to the 20$^{th}$ century average. In the Florida Everglades, a series of droughts that lasted from about 800-1200 AD were severe enough to allow tree islands to develop where sawgrass marshes existed before. Archeological evidence for human abandonment of western North American settlements suggest that the droughts decimated early agricultural efforts and forced communities to migrate to find more favorable sites.

USGS scientists are conducting studies to understand the frequency, severity and geographic extent of droughts during the last few thousand years. These studies also will provide data to understand how these events affected plant and animal communities. By gathering new data from unstudied parts of the Nation and combining it with results from earlier work, scientists are

developing large datasets needed to anticipate the impacts of future droughts on natural and built communities, agriculture, and natural resources.

**Sea Level and Ice Cover Changes**

Sea level has varied throughout Earth history in response to a variety of processes. Over long time scales, Ice Age cycles of melting and growth of ice sheets were the primary influence on sea level. Sea level is low during glacial periods (Ice Ages) and high during warm interglacial periods (such as the present). During the peak of the last Ice Age (~21,000 years ago), an ice sheet covered an area of more than 5 million square miles, extending as far south as Illinois. Globally, sea levels during the last glaciation were 125 meters (410 feet) lower than today (Figure 4).

During the last interglacial period (~125,000 years ago), global sea level was about 8 meters (26 feet) higher than today, and geologic evidence indicates that sea level was higher than today during at least two other interglacial periods. During each period of high sea level, the Greenland and Antarctic Ice Sheets were smaller than they are now.

Since the last Ice Age, there have been instances of rapid sea level rise due to sudden releases of meltwater from ice sheets or the bursting of ice dams (Figure 5). For example, during the period referred to Meltwater Pulse 1A (14,700 – 13,500 years before present), when continental ice sheets were retreating and releasing freshwater to the oceans, sea level rose at rates greater than 4 meters (13 feet) per century.

During the last few thousand years, sea level changes have resulted from small changes in the volume of ice in glaciers and ice sheets, from changes in ocean volume due to temperature fluctuations, and from changes in ocean circulation. These factors are complex and reflect the connections among different parts of the climate system. For example, melting at the edges of ice sheets can influence ocean currents and vice-versa; warm ocean water can cause melting of submerged ice sheet edges and ice shelves.

Sea level during the last 2,000 years has fluctuated over hundred-year time scales, with differences in time and place. That is, the pattern that one sees depends on where and when one looks. The relationships between sea level, temperature, and glacier melting during that time are unclear. These uncertainties, and the potential impact of changes to the Greenland and Antarctic ice sheets, make it difficult to project near-term patterns of sea level. Studies of present day relative sea levels are complicated by natural and man-made confounding factors (e.g., practices that contribute to local subsidence, as well as geologic factors). For these reasons, reconstructing past relative sea levels along different coasts, correlating them with temperature reconstructions, and interpreting causal mechanisms is a priority research area.

**Carbon Cycle Variability**

Carbon dioxide ($CO_2$) and methane ($CH_4$) occur naturally in the Earth's atmosphere and interact with the land and oceans to affect climate on both short (years to decades) and long (thousands to millions of years) time scales. $CO_2$ is taken up and released by the ocean on various timescales, related to ocean biological productivity, ice volume, carbonate production and dissolution, and ocean temperature. On longer timescales, $CO_2$ can vary depending on the amount of volcanic

activity, mountain building, and geologic weathering. To a lesser extent, $CO_2$ is controlled by uptake and release by soils and plant growth and decomposition on land. Methane concentrations are controlled primarily by the terrestrial biosphere, namely the extent of both tropical and high latitude wetlands, permafrost formation and degradation, and biomass burning. Methane production increases with increasing soil inundation and temperature.

Direct measurements of past atmospheric carbon dioxide and methane (i.e., $CO_2$ and $CH_4$) levels come from trapped "fossil" air recovered from ice cores. The longest ice cores come from Antarctica, where 3200 meter long (nearly 2 mile thick) ice core records span the last 800,000 years, or the last eight ice ages (Figure 2). Over these long time scales, atmospheric $CO_2$ has fallen and risen by its uptake and release, respectively, to and from the world's oceans and atmosphere, and, to a lesser extent, the terrestrial biosphere. During the last 500,000 years, Ice Age $CO_2$ concentrations were 190-200 parts per million volume (ppmv), compared to 280 ppmv during the warmer interglacial periods. $CH_4$ in the atmosphere over the last 800,000 years ranges from ~350-450 ppbv during glacials to 680-780 ppbv during interglacials. Concentrations of methane are slightly higher in the Greenland ice cores than the Antarctic ice cores, in what is known as the interpolar gradient, because land area, and therefore methane production, is higher in the northern hemisphere.

Direct measurement of greenhouse gas concentrations from ice cores provides a context to evaluate modern measurements from the atmosphere. More poorly understood elements of the carbon cycle include: 1) how the storage and release of carbon in soils is affected by external factors, such as temperature, altered wetland hydrology, and land cover changes and 2) the feedbacks between carbon cycle change and climate. Soils, particularly wetland and permafrost soils, are the largest terrestrial reservoirs of organic carbon and contain more than twice the amount of carbon currently in the atmosphere. During the transition from the last Ice Age to the present interglacial (from ~14-10 thousand years), permafrost thaw rates were the highest of the last 20,000 years and released carbon from soils into the atmosphere. Studies of long-term patterns of carbon storage capacity in low-lying coastal wetlands in eastern North America indicate changes in carbon accumulation rates occurred during both Medieval time (AD 800-1200) and the Little Ice Age (AD 1500-1850), and research is underway to determine how land-use changes since Colonial times (such as deforestation, drainage of wetlands) affected carbon storage in soils.

**Implications of past variability for management of natural resources**

By integrating geological and instrumental records of past climate, scientists are determining how terrestrial and marine systems and their biota were affected by a broad range of changes throughout Earth history. These records provide data on how different parts of the system respond to changing temperature, water availability, ice cover, and sea level, among other things. They also provide insights on how external factors, such as volcanic eruptions, solar variability, concentration of atmospheric greenhouse gases, and land cover change, affect climate, land, and oceans. Scientists at the USGS and other institutions across the globe are conducting a wide range of research to develop datasets and tools needed to understand and forecast how different sectors of our Nation are affected by a variety of factors. This approach is grounded in field and laboratory research and modeling, and aims to provide clear, unbiased science to land managers

and decision makers to assist them in efforts to be responsible stewards for our Nation's resources.

**CONTACT**: Debra Willard, Program Coordinator for Climate and Land Use Change Research and Development, 703-648-5320, dwillard@usgs.gov

## FIGURES

Figure 1 – Global deep-sea oxygen and carbon isotope records compiled from more than 40 sites around the globe indicate substantial climate variability over the last 65 million years. The present configuration of continents and oceans has been in place for approximately the last 3 million years, after closure of the Panama Seaway. The temperature scale was calculated based on an ice-free ocean and applies only to the time before onset of significant Antarctic glaciation, which began around 35 million years ago. The temperatures are derived from their inverse relationship with the ratio of the abundance of two oxygen isotopes, denoted by $\delta^{18}O$. $\delta^{13}C$ is a measure of the abundance of two carbon isotopes and can provide information on the relative prevalence of different types of vegetation. Figure from Zachos et al., 2001.

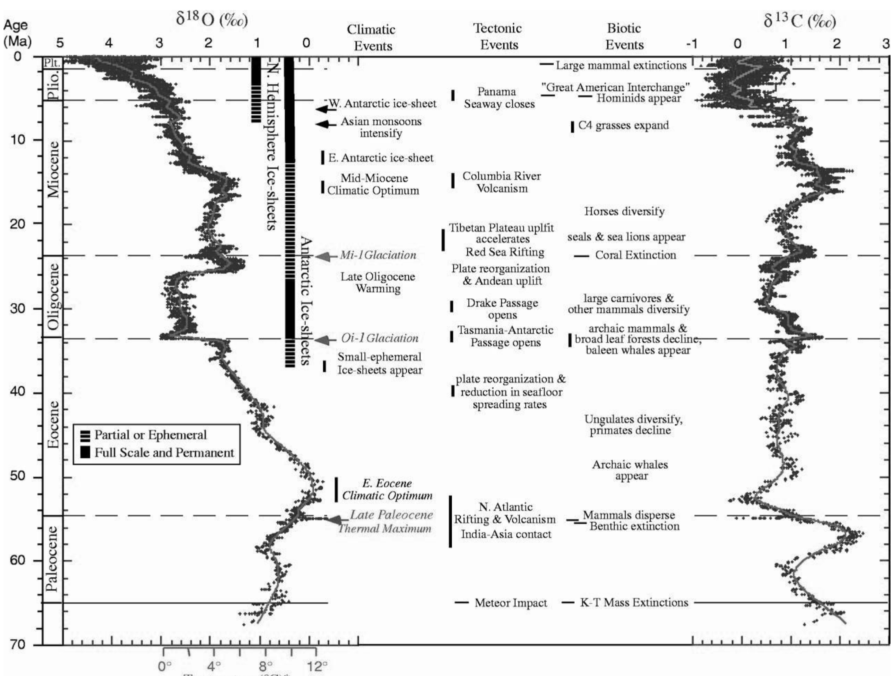


**Figure 2** – Carbon dioxide ($CO_2$), temperature, and other environmental parameters fluctuate between Ice Age (glacial) and warmer interglacial periods. This figure shows $CO_2$ records and temperature anomalies from the EPICA Dome C in Antarctica over the last 800,000 years (from Lüthi et al., 2008). Surface temperature anomalies were calculated relative to the mean temperature of the last millennium (indicated by dashed line) (Jouzel et al., 2007). Data for $CO_2$ are from Dome C. Horizontal lines indicate mean values of temperature and $CO_2$ for the following time periods: 799-650 kyr, 650-450 kyr, 250-270 kyr, and 270-50 kyr.

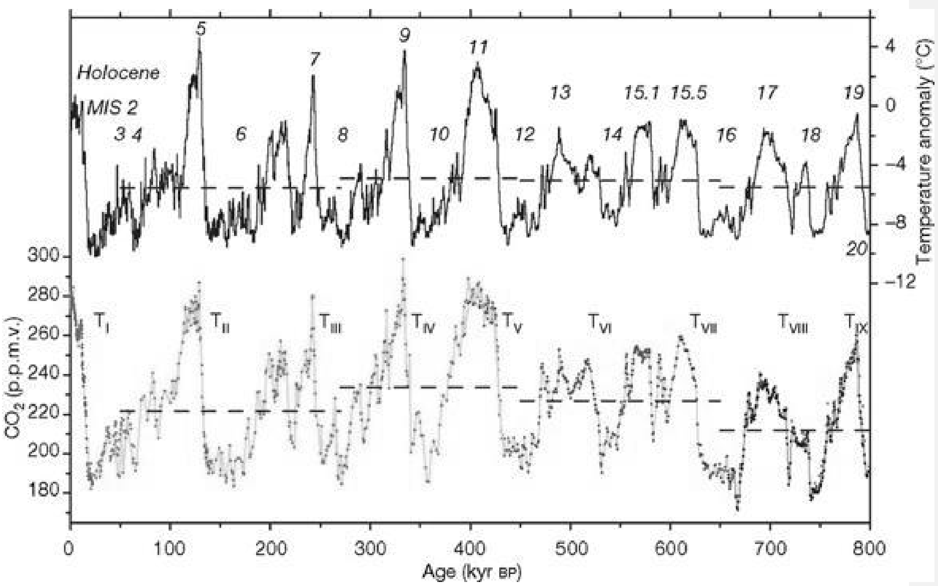


Figure 3 – Changes in configuration of the Laurentide Ice Sheet (light blue), surface water (dark blue), and sea level from the Last Glacial Maximum (21,000 years ago), early Holocene (11,000 years ago), mid-Holocene (7000 years ago), and the present. During the maximum glaciation, sea level was up to 120 meters lower than present, and the Florida peninsula was much more extensive (modified from Bartlein et al., 2014).

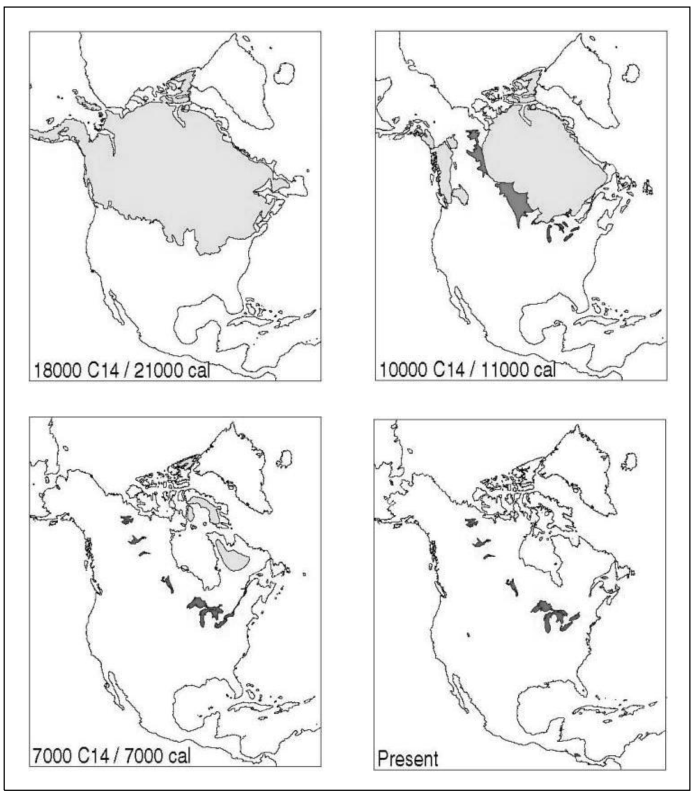


Figure 4. Reconstructed 25-year mean streamflow of the Colorado River at Lee Ferry from AD 762-2005, plotted as percentage of the 1906-2004 mean of observed natural flows, with the 100% flow level equaling the 1906-2004 mean (from Meko et al., 2007). During an extended drought in the mid-1100's, mean annual streamflow decreased by more than 15%. The horizontal dashed line (at 87%) represents the lowest 25-year mean for the observed period (1906-2004), which corresponds to the period from 1953-1977.

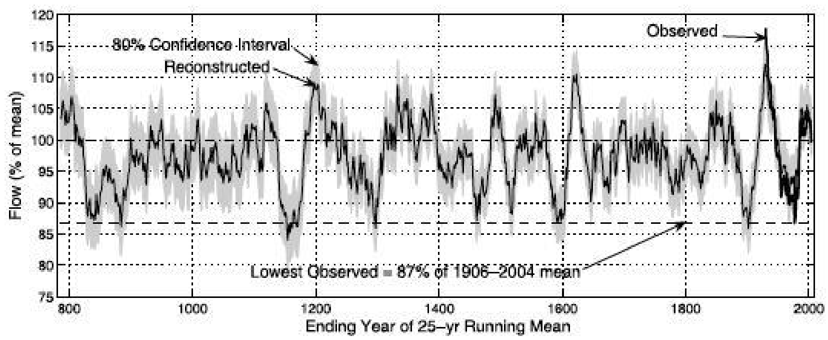


Fig. 5. Relative sea level curve for Barbados over the past 32,000 years (from Peltier et al., 2015), showing rise in sea level as the extensive ice sheets of the last Ice Age melted between about 17,000 to 8,000 years ago (a relative sea level of 0 meters represents the present day). Green bars represent sea-level index points based on four species of coral that were dated using Uranium-thorium dating (a technique that provides ages of carbonate materials such as corals over the past 500,000 years).

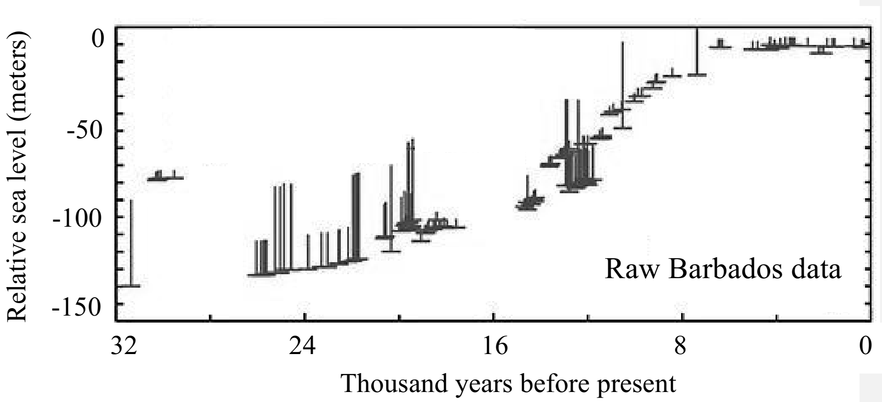
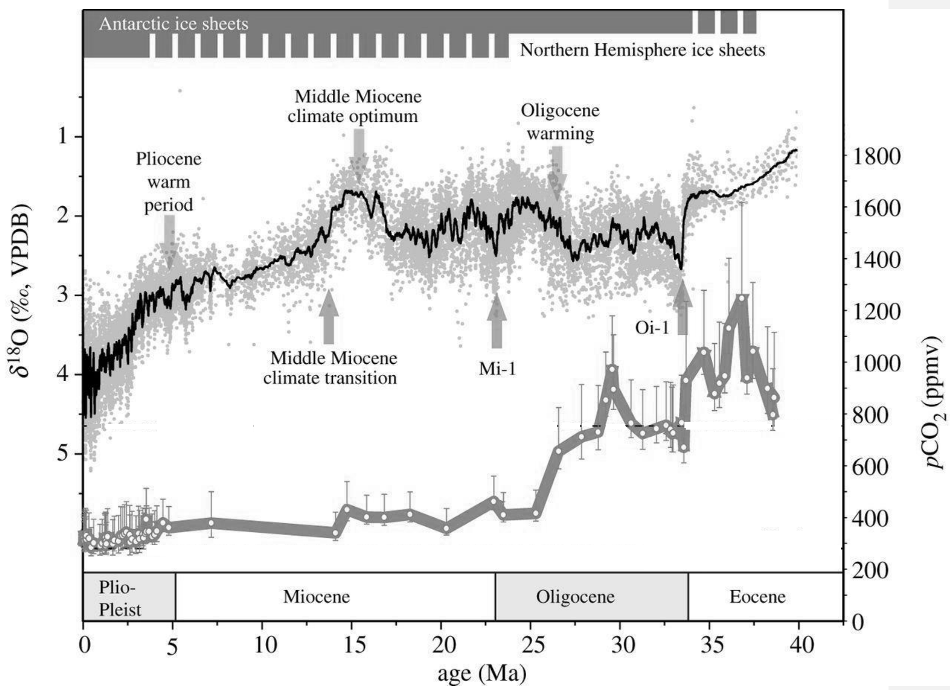


Figure 6. Climate and atmospheric $CO_2$ history for the past 40 million years. The benthic $\delta^{18}O$ curve is a stacked compilation of data from deep-sea benthic foraminifers from sites around the world and is inversely correlated with changes in ocean temperature, that is, temperature increases as we go up the x-axis, but $\delta^{18}O$ decreases. (from Zachos et al., 2008). The $pCO_2$ (partial pressure of atmospheric $CO_2$) reconstruction is based on measurements of alkenones (organic molecules produced by some species of marine algae) from Ocean Drilling Program Site 925 on Ceara Rise in the western equatorial Atlantic Ocean. Major warming (red arrows) and cooling (blue arrows) events are labelled. Red bars indicate brief history of Antarctic and Northern Hemisphere ice sheets. (Figure modified from Zhang et al., 2013)



**References**

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Zachos, J.C., Dickens, G.R., Zeebe, R.E., 2008, An Early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics: Nature, v. 451, p.  279-283.

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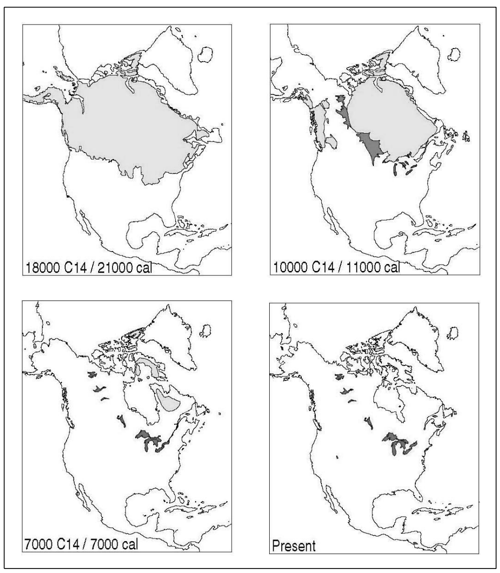

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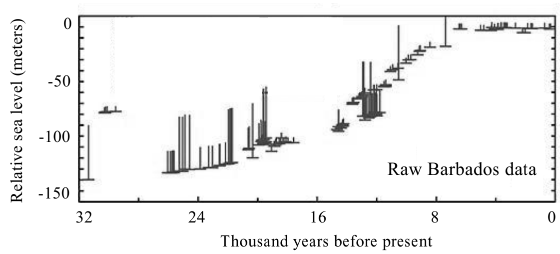

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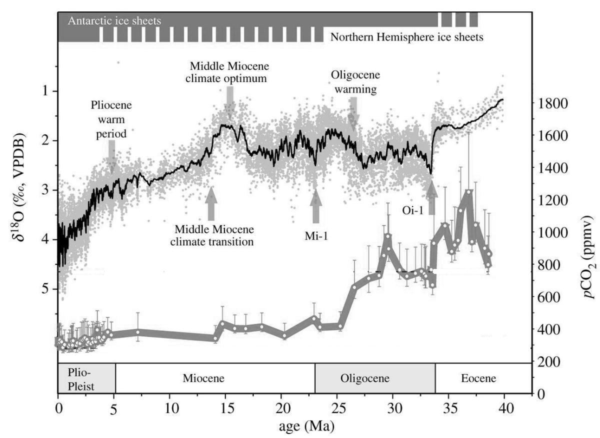

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**To:** Goklany, Indur[indur_goklany@ios.doi.gov]
**From:** Willard, Debra
**Sent:** 2017-06-07T11:29:46-04:00
**Importance:** Normal
**Subject:** Re: Earth's climate history briefing
**Received:** 2017-06-07T11:29:53-04:00

Goks,
Thanks - [redacted] (b)(5)
Should be able to get it back this afternoon or early tomorrow at the latest.

Best,
Deb

---------------------------------------------------------------------------------
Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Wed, Jun 7, 2017 at 11:25 AM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Debra,
My comments are on the attached. [redacted] (b)(5)

(b)(5)

Thanks. I also have enjoyed working on thsi and learning something new.

Best,
Goks

On Tue, Jun 6, 2017 at 11:46 AM, Willard, Debra <dwillard@usgs.gov> wrote:

Hi Goks,
I've attached the revised briefing document. [redacted] (b)(5)

(b)(5)

[redacted]

Thanks for your helpful comments; I enjoyed pulling this together.

Regards,

Deb


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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone:   703-648-5320
e-mail:  dwillard@usgs.gov
https://profile.usgs.gov/dwillard


On Mon, Jun 5, 2017 at 7:24 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

[redacted] Let's continue this tomorrow. Thanks

On Mon, Jun 5, 2017 at 5:07 PM, Willard, Debra <dwillard@usgs.gov> wrote:

[redacted]


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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone:   703-648-5320

e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 4:00 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Debra,

[redacted]

I was going to call but didn't have your home number.

In the attached, I have made changes that we discussed, [redacted]

Thanks.

Goks

On Mon, Jun 5, 2017 at 2:23 PM, Willard, Debra <dwillard@usgs.gov> wrote:

Peltier_et_al-2015-Journal_of_Geophysical_Resea...

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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone: 703-648-5320
e-mail: dwillard@usgs.gov
https://profile.usgs.gov/dwillard

On Mon, Jun 5, 2017 at 2:03 PM, Goklany, Indur <indur_goklany@ios.doi.gov> wrote:

Hi Debra-- I just called you but you weren't in. Call me when you can. Thanks -- Goks (202-208-4951)

On Mon, Jun 5, 2017 at 9:39 AM, Willard, Debra <dwillard@usgs.gov> wrote:

Hi Goks,

I forwarded the attached document upstairs last week; I haven't received the final go-ahead on it, but I'm attaching it here for you to look over. Please consider it a near-final draft, and note that I have left the "From" line blank until I get further instructions. [redacted]

[redacted] In the interest of conserving space, I did not include citations in the text, but I can provide those if needed.

Please let me know if you have further questions.

Best,

Deb

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Debra A. Willard, PhD
US Geological Survey
Coordinator, Climate Research & Development Program
12201 Sunrise Valley Drive, Rm 4B 318
926A National Center
Reston, VA 20192
phone:   703-648-5320
e-mail:  dwillard@usgs.gov
https://profile.usgs.gov/dwillard

**To:** Bowling, Ross (OS/ASA)[Ross.Bowling@hhs.gov]; Patel, Sandeep (OS/ASA)[Sandeep.Patel@hhs.gov]; amy.p.kaminski@nasa.gov[amy.p.kaminski@nasa.gov]; Kuang, Jennee[kuang.jennee@epa.gov]; lynn.buquo@nasa.gov[lynn.buquo@nasa.gov]; Meador, Jarah[Jarah.Meador@va.gov]; thomas.feucht@usdoj.gov[thomas.feucht@usdoj.gov]; James.Grove@HQ.DHS.GOV[James.Grove@HQ.DHS.GOV]; Garson, Jennifer[Jennifer.Garson@hq.doe.gov]; Walker, Traci L. EOP/OMB [redacted] (b)(6)-White House Staff phsue@ftc.gov[phsue@ftc.gov]; heather.evans@nist.gov[heather.evans@nist.gov]; dpremo@cns.gov[dpremo@cns.gov]; pdavis@cpsc.gov[pdavis@cpsc.gov]; Whitney, Tyson - OCFO[Tyson.Whitney@cfo.usda.gov]; Martin.D.Dubroff@hud.gov[Martin.D.Dubroff@hud.gov]; Grace Hoerner[ghoerner@usaid.gov]; Goklany, Indur[indur_goklany@ios.doi.gov]; Buquo, Lynn (JSC-SA511[lynn.buquo-1@nasa.gov]; Daffan, Kathleen[kdaffan@ftc.gov]; Burton, Martha (USDA.GOV)[martha.burton@cfo.usda.gov]; Kelly Olson - XAAB[Kelly.Olson@gsa.gov]; Tammy White - XAAB-C[tammyj.white@gsa.gov]; Bogusz, Diane (HHS/ASA)[Diane.Bogusz@hhs.gov]
**Cc:** Phelps, Randy L.[rphelps@nsf.gov]
**From:** Palacios, Albert
**Sent:** 2017-06-07T17:21:46-04:00
**Importance:** Normal
**Subject:** RE: Agency Prize/Challenge Leads Meeting
**Received:** 2017-06-07T17:29:27-04:00
ACTE_Challenges.pptx
dup_819_thecraftofincentiveprizedesign_sm.pdf

Hello All,

Attached are the presentation I mentioned in our meeting as well as the report from Deloitte from which I derived my text for the slides. The information in the 2015 PPT is outdated as we have already completed two of the challenges mentioned in the presentation. The “Why Challenges” section (Slides 13-17) are the most relevant. Just prior to that I contrast how challenges differ from typical procurement processes. You can ignore the rest of the content as it was directed to an audience of educators. I hope someone finds this information useful. It may or not apply to your agency. Please feel free to comment or disparage as needed. ;-)

Thanks,
Albert

-----Original Appointment-----
**From:** Bowling, Ross (OS/ASA) [mailto:Ross.Bowling@hhs.gov]
**Sent:** Thursday, April 20, 2017 10:39 AM
**To:** Bowling, Ross (OS/ASA); Patel, Sandeep (OS/ASA); amy.p.kaminski@nasa.gov; Kuang, Jennee; lynn.buquo@nasa.gov; Meador, Jarah; thomas.feucht@usdoj.gov; James.Grove@HQ.DHS.GOV; Garson, Jennifer; Walker, Traci L. EOP/OMB; phsue@ftc.gov; heather.evans@nist.gov; dpremo@cns.gov; pdavis@cpsc.gov; Whitney, Tyson - OCFO; Martin.D.Dubroff@hud.gov; Grace Hoerner; Goklany, Indur; Palacios, Albert; Buquo, Lynn (JSC-SA511; Daffan, Kathleen; Burton, Martha (USDA.GOV); Kelly Olson - XAAB; Tammy White - XAAB-C; Bogusz, Diane (HHS/ASA)
**Cc:** Phelps, Randy L.
**Subject:** Agency Prize/Challenge Leads Meeting
**When:** Tuesday, June 06, 2017 1:00 PM-2:30 PM (UTC-05:00) Eastern Time (US & Canada).
**Where:** HHS Humphrey Building, 200 Independence SE, Conference Room 425A; 1-866-817-9588, participant code 6111777

Agenda

- Introductions: 10 min
- Prizes/challenges in the current administration: 30 min
- How new agency leadership views prizes/challenges
- New opportunities or barriers
- Status of agency policies on use of prizes (HHS example attached)
- Evolving models of prizes/challenges: 25 min
- Latest trends on types, structures, or purpose of challenges. E.g. international bi-lateral challenges, challenges leveraging govt data
- Web of prize vendors and contractors: 20 min
- Honest discussion on the landscape of available prize vendors
- Host and topics for next meeting: 5 min

U.S. Department of Education
Office of Career, Technical, and Adult Education
Division of Academic and Technical Education

# Advancing Innovation in CTE

CareerTech Vision

November 20, 2015

# Innovation

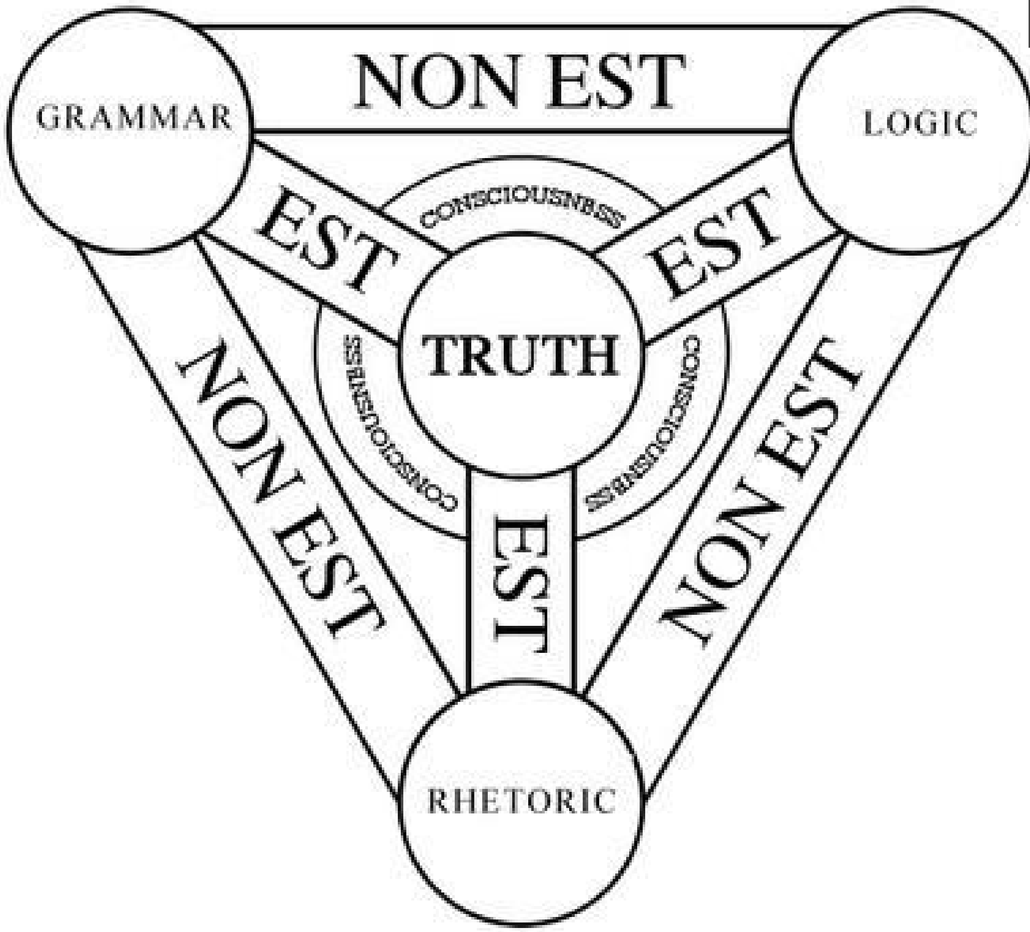
Bringing something new
to something established

# Innovation

Trivium

Input

Process




Output

# Our Trivium

1. Inputs

   *Our resources*

2. Process

   *How we apply our resources*

3. Outputs

   *The results from applying our resources*

***Innovation requires rethinking each of these***

# Our Trivium

1. Inputs

   *IAA, Public/Private, Intangibles*

2. Process

   *Procurements, Partnerships, Allocation*

3. Outputs

   *Rethinking Success*

***Innovation requires rethinking each of these***

# Inputs

1. Perkins Legislation and Budget
2. Interagency Collaboration
3. Executive Branch
4. Philanthropic
5. Private Industry
6. Intangibles
   - Convening
   - Communicating

# Process

1. National Activities
   - Grants
   - Contracts
2. Procurement and Acquisition
3. Strategic Partnerships

# Outputs

1. Performance Measures
2. Maximizing Reach
3. Maximizing Effectiveness
4. Moving the Needle

# Traditional Procurements

1. Develop Statement of Work / Grant
2. Request Proposals
3. Evaluate Proposals
4. Award Contract / Grant
5. Period of Performance
6. Product or Outcome

# Innovative Procurements

1. Develop Objectives
2. Communicate Goals
3. Solicit Products and Solutions
4. Evaluate Products
5. Identify the Best Models
6. Recognize and Share the Models

# Open Innovation Prize Challenges

1. Develop Objectives
2. Communicate Goals
3. Solicit Products and Solutions
4. Evaluate Products
5. Identify the Best Models
6. Recognize and Share the Models

# Why Challenges

Inspire new ideas, technologies and solutions

Democratize solutions and engage the public

# Why Challenges

Pay only for success and establish an ambitious goal without having to predict which approach is most likely to succeed

# Why Challenges

Reach beyond the “usual suspects” to increase the number of solvers tackling a problem and to identify novel approaches, without bearing high levels of risk

# Why Challenges

Bring out-of-discipline perspectives to bear

# Why Challenges

Increase cost-effectiveness to maximize the return on taxpayer dollars

# What We Heard

- State of technology in education
- Importance of career counseling
- Increasing access to CTE
- Perceived stigma of CTE

# Reach Higher Career App Challenge

**Prize Pool $225,000 + $250,000**

**Purpose:** To conduct a prize competition to identify the best app that provides personalized career and education information to students while strengthening their relationships with school-based counselors.

**Outcomes:** One winning app and four finalist apps that can be used as models for further development or implementation.

**Important Dates:** Launched – October 7, 2015
Finalists Announced – February 2016
Winners Announced – Summer 2016

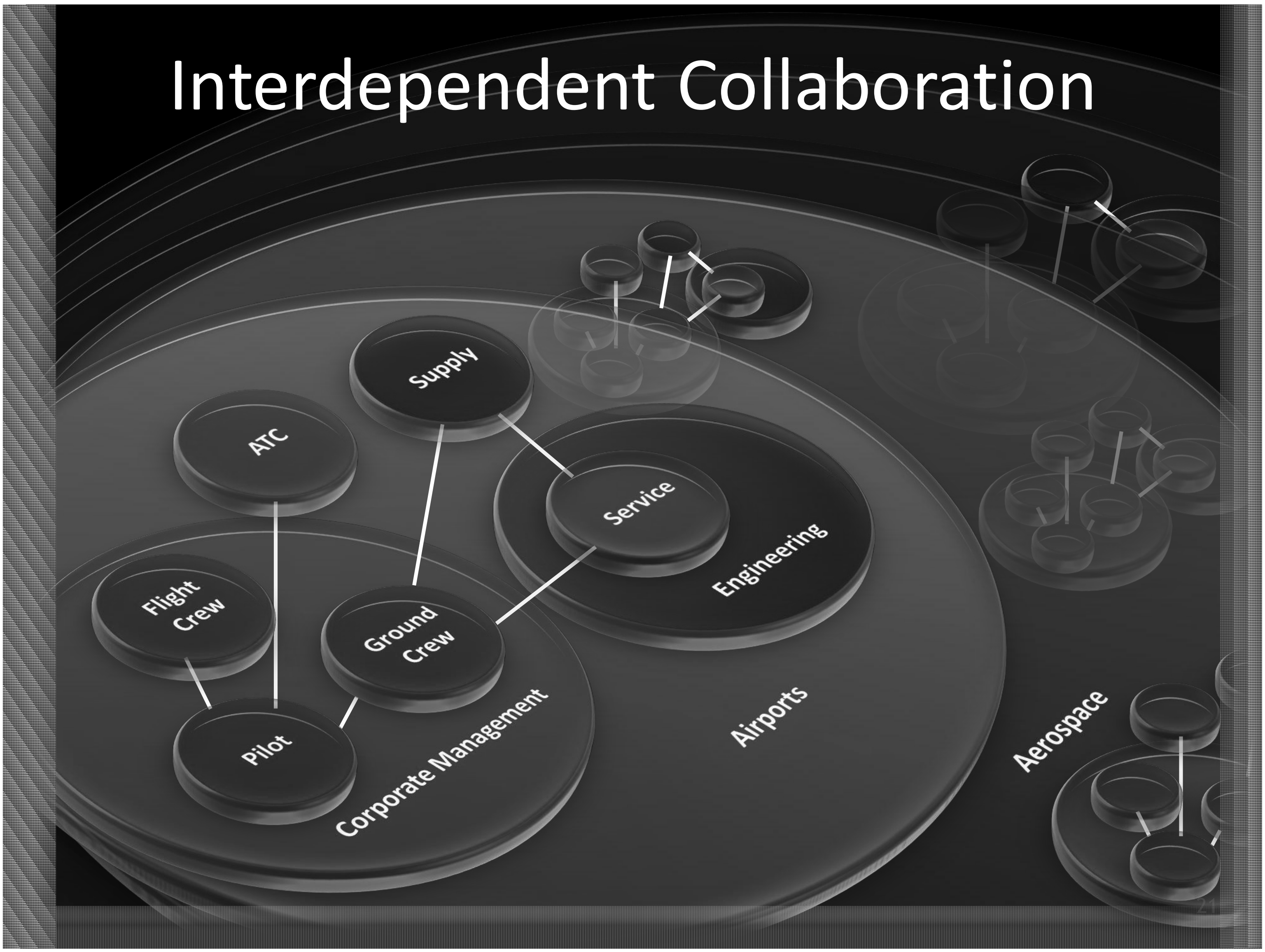
# EdSim Challenge

**Prize Pool $680,000 + ~$300,000**

**Purpose:** To conduct a prize competition to identify 3D immersive simulations that can effectively deliver CTE instruction while establishing design standards for next generation education simulations.

**Outcomes:** One winning simulation and four finalists that can be used as models for further development or implementation.

**Important Dates:** Launch – November 2015<br>Finalists Announced – March 2016<br>Winners Announced – June 2016


Interdependent Collaboration
Supply
ATC
Service
Engineering
Flight Crew
Ground Crew
Pilot
Corporate Management
Airports
Aerospace

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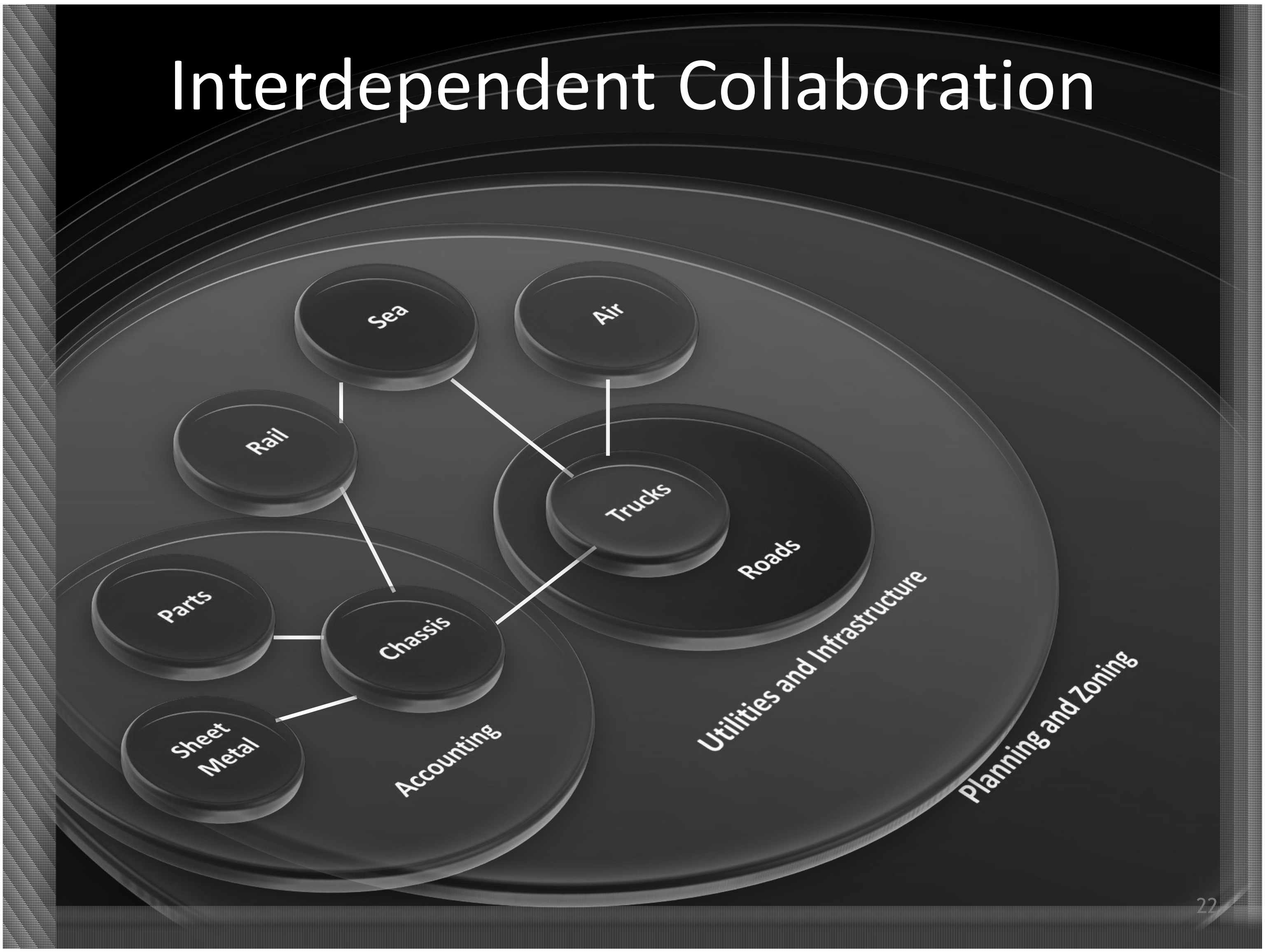

# Makerschool Challenge

**Prize Pool $200,000 + ?**

**Purpose:** To conduct a prize competition to transform existing CTE facilities, or create mobile innovation spaces, that integrate "making" into multidisciplinary curricula.

**Outcomes:**

A cohort of Makerschools that results in a library of models that can be implemented and adapted.

**Important Dates:** Launch – January 2016
Cohort Announced – March 2016
National Maker Faire – June 2016

For More Information
Visit EdPrizes.com

**http://www.EDPrizes.com**

# Takeaways

- Visit EdPrizes.com
- Register for Email Updates
- Enter the Reach Higher Career App Challenge *(Dec. 7)*
- Provide your Feedback to EdSim *(Dec. 9)*
- Think Makerschool for Spring 2016

# ?s

# For More Information

**EdPrizes.com**

**Albert.Palacios@ed.gov**

Notes Summary:

No speaker notes are contained in this presentation.